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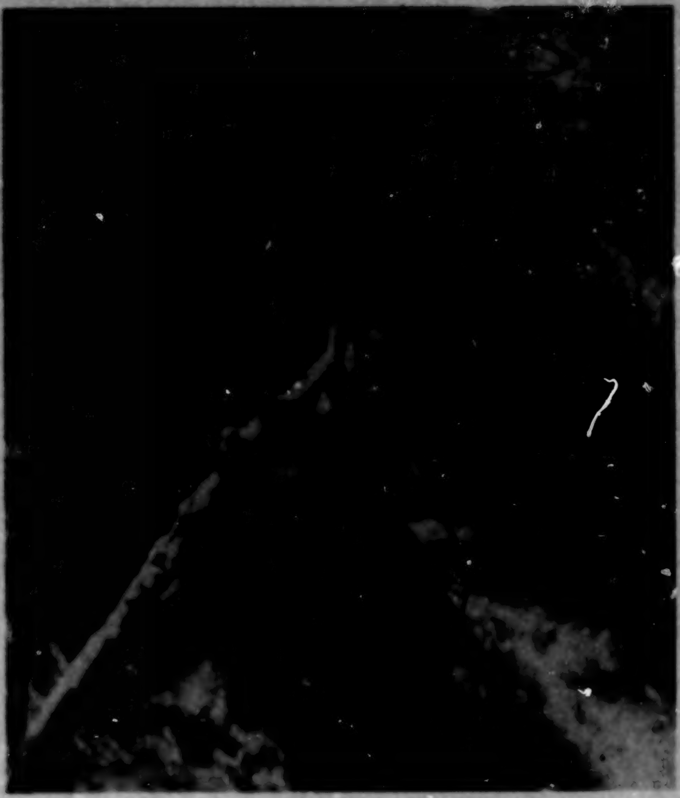
NASA Conference Publication 2490

Space Construction



Proceedings of a conference held at
NASA Langley Research Center
Hampton, Virginia
August 6-7, 1986

NASA

(NASA-CP-2490) SPACE CONSTRUCTION (NASA) N88-10870
308 p Avail: NTIS HC A14/MF A01 CSCL 22B --THRU--
N88-10882
Unclas
H1/18 0106069

NASA Conference Publication 2490

Space Construction

Edited by
Jane A. Hagaman
Langley Research Center
Hampton, Virginia

Proceedings of a conference sponsored by the
Offices of Space Flight, Aeronautics and
Space Technology, and Space Station, NASA
Headquarters, Washington, D.C., and held at
NASA Langley Research Center
Hampton, Virginia
August 6–7, 1986

NASA
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INTRODUCTION

On November 26, 1985 the Space Shuttle Atlantis embarked on a historic mission. A major objective of the flight of STS 61-B called for the Orbiter Atlantis to carry to orbit as a part of its payload the EASE/ACCESS NASA flight demonstration. On both the third and fifth days of the seven day mission of STS 61-B, Mission Specialists Jerry Ross and Woody Spring assisted by the Commander Brewster Shaw, Pilot Bryan O'Conner and Mission Specialist Dr. Mary Cleave conducted over 12 hours of intense extravehicular activity which opened the era of space construction.

The NASA Headquarters Offices of Space Flight, Aeronautics and Space Technology, and Space Station sponsored this Space Construction Conference. The purpose of the conference was to present to the aerospace community an in-depth review of the EASE/ACCESS flight demonstration. In addition, the conference gave NASA the opportunity to present the status of activities regarding future space flight experiments and accompanying technology developments that will demonstrate the capability of on-orbit construction of the Space Station.

The proceedings of the Space Construction Conference are structured to provide the reader with some background behind the EASE/ACCESS mission; a description of the EASE/ACCESS hardware development; a review of the hardware integration process; a review of the crew training and procedure development associated with the EASE/ACCESS demonstration; and finally an in-depth review of the results of the flight from the viewpoints of both the principal investigators and the crew. The proceedings conclude with papers on future NASA plans for space construction.

AGENDA

August 6, 1986

8:00-9:00 a.m.	Introduction	
	LaRC Welcome	
	Code M Opening Remarks	Ivan Bekey, HQ
	Code R Opening Remarks	Samuel L. Venneri, HQ
	Code S Opening Remarks	William T. Tumulty, HQ
9:00-10:00 a.m.	Background	
	R&T Background	Dr. Martin M. Mikulas, Jr., LaRC
	Process	George M. Levin, HQ
10:00-10:15 a.m.	Break	
10:15-12:45 p.m.	Hardware	
	EASE	Robert S. Wolf, MIT
	ACCESS	John F. Rogers, LaRC
	MPESS	Robert Hill, Teledyne Brown Engineering
12:45-1:45 p.m.	Lunch	
1:45-4:15 p.m.	Integration	
	MSFC	Gerald W. Hawkins, MSFC
	JSC	Charles E. Chassay, JSC
	KSC	Ana M. Villamil, KSC
3:15-3:30 p.m.	Break	
3:30-4:15 p.m.	Panel Discussion	
4:15-5:15 p.m.	Training & Procedure Development	
	NBF	Vygantas P. Kulpa, MSFC
	EVA Prep	Kathryn A. Havens, JSC

AGENDA

August 7, 1986

8:30-10:30 a.m.	Results	
	ACCESS	Walter L. Heard, Jr., LaRC
	EASE	David L. Akin, MIT
	Crew	
	EVA	Captain Jerry L. Ross, JSC
	Use of MFR	Mary L. Cleave, JSC
10:30-10:45 a.m.	Break	
10:45-11:15 a.m.	Results of Biomedical Data	David J. Horrigan, JSC
11:15-12:45 p.m.	Video of Flight	PI's Leading: Astronauts Contributing
12:45-1:45 p.m.	Lunch	
1:45-3:15 p.m.	Panel Discussion (Panel with Astronauts and PI's)	
3:15-3:30 p.m.	Break	
3:30-5:00 p.m.	Future Plans	
	SAVE	Richard A. Russell, LaRC
	A&R (Space Construction)	Alfred J. Meintel, Jr., LaRC
	Closing Remarks	George M. Levin, HQ

RESEARCH PROGRAM ON LARGE SPACE STRUCTURES

Dr. Martin M. Mikulas, Jr.
NASA Langley Research Center

PAPER NOT SUBMITTED FOR PUBLICATION

N88-10871

THE FLIGHT DEMONSTRATION PROGRAM AND SELECTION PROCESS

G. M. Levin
NASA Headquarters
Washington, DC

SPACE CONSTRUCTION CONFERENCE
AUGUST 6-7, 1986

Introduction:

In October 1983 the Office of Space Flight at NASA Headquarters established a new program office to: undertake a series of developments which would support program objectives of the Office of Space Flight; give younger NASA engineers "hands on" experience with the development of flight hardware; lead to new business for the Space Transportation System (STS); and stimulate present customers of the STS towards more efficient use of the unique capabilities of the space shuttle. The Flight Demonstration Program was initiated by undertaking the development of six demonstrations. The first of these demonstrations, the Orbital Refueling System was successfully flown on STS 41-C on August 29, 1984. The second and third Flight Demonstrations, EASE and ACCESS, were performed successfully on STS 61-B on November 29 and December1, 1985. These latter two demonstrations, are the subject of this Space Construction Conference. Therefore, no further discussions of EASE/ACCESS is included in this paper.

In the coming years these missions will be followed by demonstrations of a voice control system for the shuttle's closed circuit television system, an infrared intercommunications system, a plasma motor/generator proof of function demonstration, the implementation of a force feedback device on the shuttle's remote manipulator system, the transfer of super fluid helium on-orbit, a laser docking sensor and a small expendable deployment system.

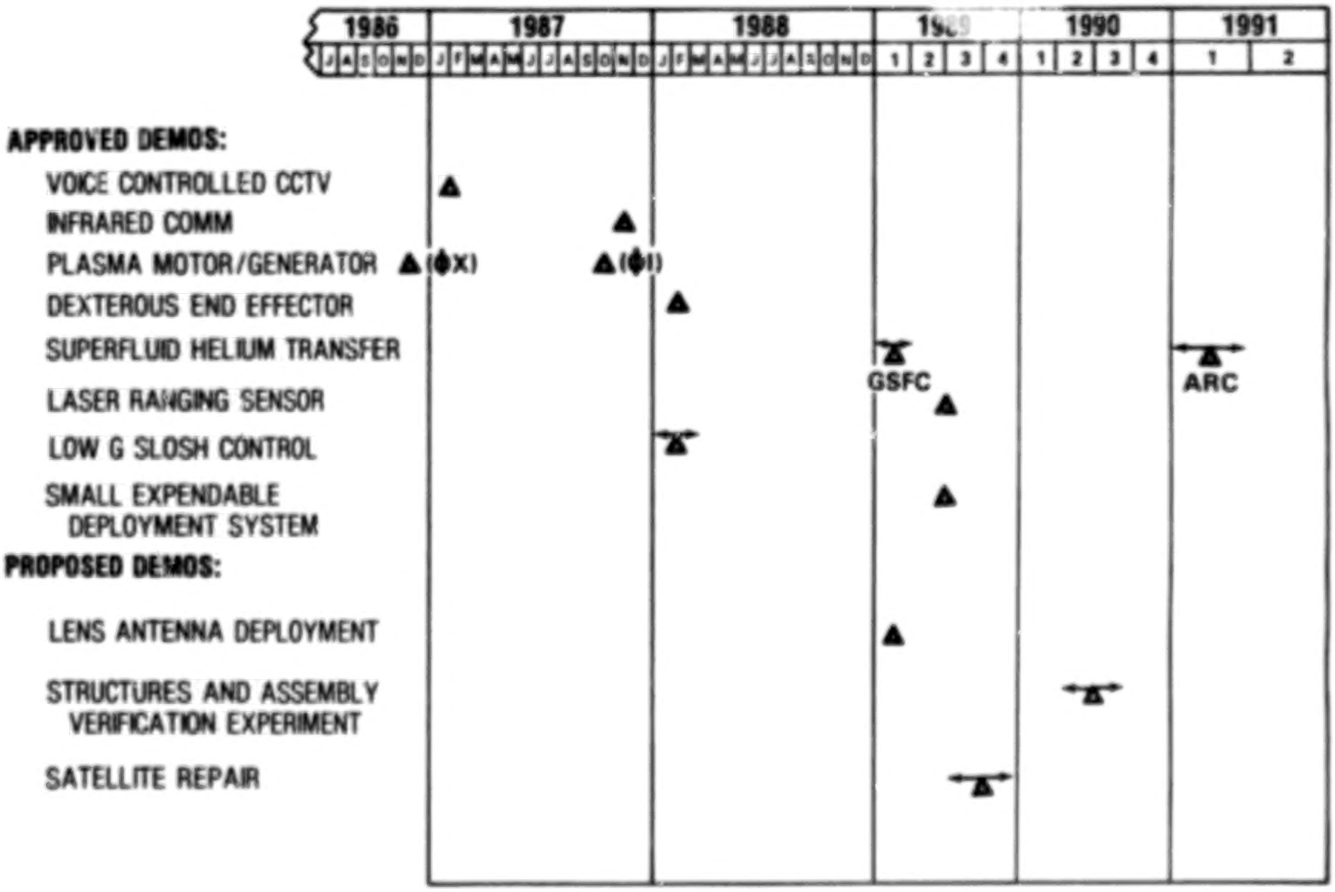
Flight Demonstrations are selected annually by the Flight Demonstrations Office in the Office of Space Flight. Responsive to a solication issued by the Flight Demonstrations Office, proposals for NASA funded Flight Demonstrations are submitted to NASA Headquarters in July of each year. These proposals undergo a peer review with the final selection announced by the Associate Administrator for Space Flight in October. The Flight Demonstrations Program also participates with the Department of Defense (DoD) in the management and manifesting of DoD Flight Demonstrations.

Typical areas of emphasis for Flight Demonstrations are:

Space Construction/Large Space Structure
Expendable Resupply
System Improvement
Satellite Servicing
Tether Applications

The proposed flight readiness dates for future OSF flight demonstrations are shown in Figure 1.

FLIGHT READINESS SCHEDULE FOR OSF FLIGHT DEMONSTRATIONS



Approved Flight Demonstrations

The Orbital Refueling System (ORS)

The Orbital Refueling System was the first Flight Demonstrations Program sponsored by the Office of Space Flight. The objectives of the ORS were to develop and demonstrate the equipment and procedures for a hydrazine fuel transfer system; to develop and demonstrate the tools needed to interface with existing satellites to accomplish fuel transfer; and to develop and evaluate specific procedures to refuel present satellites of the Landsat type.

The ORS consisted of five major categories: the structural subsystem; the fluid subsystem; the avionics subsystem; the thermal control subsystem; and the EVA tools. The ORS tankage unit (with its fuel tanks, piping, valving, heaters, and avionics) was mounted on a Mission Peculiar Experiment Support Structure (MPESS) in the cargo bay of the orbiter. In the demonstration configuration the ORS was capable of multiple transfers of approximately 200 pounds of hydrazine fuel. The ORS could be modified to deliver approximately 500 pounds of fuel to an orbiting satellite by a fuel line connected with a hydrazine servicing interface tool set. The ORS was interfaced to the Orbiter general purpose computer, and analog channels were available for data monitoring. Control of the ORS fuel transfer was from the Aft Flight Deck. During the ORS demonstration fuel was transferred through a fixed propellant bypass as well as through a fuel line connection established by an EVA crew member.

The EVA tools were the unique hardware items required to: permit access to the manual fill valve; provide redundant seals for crew safety; and control fluid flow to the satellite. The tool set consisted of seven items designed for satellite engagement, valve opening, and valve closing. The fuel transfer unit and valve, once engaged, became permanently attached to the satellite, thus providing a standard interface for refueling.

Force Torque Sensor

The goals of the Force Torque Sensor (FTS) Flight Demonstration are to demonstrate an enhanced capability of the shuttle Remote Manipulator System (RMS) in a zero "g" environment. The RMS/FTS system will measure and graphically display the forces and torques which are developed at the wrist joint of the RMS.

The RMS/FTS system design will intergrate new elements or components with existing shuttle subsystems. The new elements will include the Force Torque Sensor, the force torque sensor electronics, the sensor display subsystem, and the cabling and control panel. Existing shuttle subsystems that will be integrated with the RMS/FTS include the RMS, payload bay cabling, a closed circuit TV flight monitor, power and air conditioning.

The FTS housing will contain the FTS electronics and will be mounted as an integral part of the RMS. The FTS will be installed between the end of the RMS and the base of the standard end effector. The sensor display system will be located in the crew compartment and will comprise a microcomputer and graphics generator. The sensor display system will process signals from the FTS and resolve the forces and vectors will be graphically displayed on a Shuttle TV flight monitor.

Plasma Motor/Generator (PMG) Proof of Function

The objective of this experiment is to provide order-of-magnitude verification of the key physical processes involved in utilizing the Earth's magnetic field, the velocity of the shuttle and a conductor either to generate a voltage or a mechanical force (electrical generator or motor).

The results of this experiment would provide the first firm performance data to guide planning and development of hardware and experimental procedures for subsequent more extensive tests such as the Tethered Satellite System science experiments and engineering development systems. The primary uncertainty in operation of a PMG system lies in the performance of the plasma current "brushes" to complete the "armature" to ionosphere current path. The numerous variables involved in theoretical computation of the plasma physics processes result in considerable uncertainty in the results obtained. Only a direct measurement, in orbit, of the induced VXB voltage, current, coupling, and ionospheric circuit impedance can provide adequate verification that the calculated effects actually occur.

Initial verification of these fundamental issues can be obtained prior to the availability of the Tethered Satellite System by flying the 200 meter/10 watt experiment. Adequate voltage and separation from spacecraft wake effects will be achieved by the 200 meter wire, without having to deal with stabilization and retrieval systems credible zeroth-order demonstration of the hollow cathode plasma coupling vital to PMG performance will be achieved. The deployed wire and far end electronics package will be jettisoned at the completion of the experiment.

Voice Controlled CCTV Demonstration

The Voice Controlled System (VCS) is a voice-actuated control system which can be used to operate spacecraft equipment when the operator's hands (and eyes) are preoccupied with the operation of other systems. This increases the efficiency of crew operations. To demonstrate this technique, the VCS will be used by a crewman to operate the Orbiter television cameras while he is simultaneously using the Remote Manipulator System (RMS) to deploy or retrieve a payload. Since the cameras provide differing views of the payload bay and the payload during the deployment operation, normally the crewman has to remove his hands from the RMS control handles and shift his visual attention to the television control panel to select cameras and adjust their view and focus. By using the VCS, he will only have to speak certain control words into his headset to effect these tasks.

The VCS will provide control output for a command vocabulary of 100 discrete words or phrases. It will respond only to the voice of the crewman who has previously recorded his voice patterns into a memory module which is inserted into the VCS at the time of the operation.

All comands provided by the VCS will parallel those on the normal television control panel and can be overridden by the television control switches. A fail safe feature will be provided to automatically remove the VCS from the control circuits when power is removed from the VCS.

In addition to normal camera adjustments, the VCS will provide sequences of camera adjustments in response to a single command word input. These sequences of adjustments will automatically position the camera to predetermined operating conditions without requiring the attention of the crew.

Infrared Intercommunications

The Infrared Intercommunications (IR COMM) is a wireless means of communicating voice or data between two or more crewman or between crewmen and an associated wall-mounted unit which ties into the Shuttle or Space Station avionics. Information will be transferred by means of modulated infrared light radiated from tiny body-mounted diode light sources. This light will bounce off the walls and other objects in the cabin, essentially "flooding" the cabin volume and eliminating blind spots regardless of source location. The receiver will detect the light mounted anywhere within the cabin regardless of which direction the transmitter or receiver are pointed. This concept has been demonstrated both in a laboratory environment and the shuttle mock-up.

A deficiency of the presently used wireless (radio) crew communications unit is its inability to meet communications security requirements without the use of body-worn encryptors. Infrared Communications would provide that security. The IR light is effectively attenuated by the Shuttle windows; the optical energy will not interact with the electrical signals of the Orbiter wiring. An optical system would be small, wireless, and light-weight, having less of an impact on the crew. Multiple users can be readily accommodated by additional channels. In addition to providing secure communications for the crew, IR could provide the transfer of high rate biological data from the crew to a wall unit, thereby replacing the existing tape recorders. This would allow real time data analysis while maintaining full crew mobility.

The purpose of the flight experiment is to demonstrate the capability of the system to transfer voice and data without dropouts using the flooded volume technique. In addition, it will prove the adaptability of the system to a space vehicle environment which incorporates multiple users.

Superfluid Helium On Orbit Transfer

With this demonstration, we plan to transfer superfluid helium (at approximately 2°K) using 175 L dewars and under zero-g conditions.

The method to be used involves a porous plug thermomechanical pump--a simple electrical device that, due to the unique properties of superfluid helium pumps the superfluid by simply heating one end of the propus plug. The principle involved is the same as that used by the IRAS and COBE porous plug to contain superfluid helium within a dewar in zero-g.

Many current and proposed space flight projects include detectors, instruments (AXAF, COBE, LDR), and facilities (IRAS, SIRTF, GP-B) which are liquid helium cooled. For long lifetime instruments and facilities, the limiting factor is the depletion of the stored helium. For those facilities which, with refurbishment, are required to last more than 1 or 2 years (SIFTF, AXAF, LDR), a method of replenishing the liquid helium is required.

We believe that this demonstration is a natural follow-on for the hydrazine propellant refueling demonstration recently completed. The superfluid helium transfer will demonstrate another in-flight servicing capability for the shuttle.

We are currently setting up a laboratory transfer experiment at the GSFC. This experiment will further define the porous plug parameters relevant to the transfer of superfluid helium in zero-g.

Laser Docking Sensor

This proposed flight demonstration is designed to show the ability of the Laser Docking Sensor (LDS) to provide real time data as an aid in a manual docking procedure. Rendezvous and docking parameters along with a three-dimensional target attitude simulation will be available as a visual display provided by the flight qualified grid computer. The crew may use this data as their basis for performing the approach to the target. The LDS system will provide azimuth and elevation angles as well as range to retroreflectors placed in a known configuration on the target vehicle.

By knowing these parameters, a plane can be defined whose orientation represents the attitude (roll, pitch, yaw) of the target with respect to the sensor/active vehicle axes. This information, provided at a real time rate (about 3-5 Hz), will enable an optimum approach trajectory to be calculated and followed either manually, as a visual aid to the crew, or automatically, by providing the information to the existing onboard navigation computers.

The LDS comprises an illuminating laser source that will either scan over or flood the field of view. This will provide the high signal to noise ratio required to maintain the accuracy of the system. A retroreflector configuration will be attached to any target vehicle in a known configuration of known dimensions to allow the calculations of unambiguous attitude. Ranging will be accomplished by modulating the laser source in either a pulsed fashion (pulsed or chirped ranging) or a CW fashion (tone ranging). Present technology will provide range accuracy to approximately one percent of range. A receiver with accompanying optics will detect the modulated return from the retroreflectors.

The operational scenario will consist of scanning the full field of view until the retroreflectors are encountered. Each retroreflector, in turn, will be located in angle and range. The sensor will then enter the track mode which consists of performing small, fast dither scans over the last known location of each reflector. Reflector movements will be then detected to allow the calculation of attitude, angle, rate, range and range rate relative to the active vehicle.

Small Expendable Deployment System

This proposed tether applications Flight Demonstration will check-out and validate the Small Expendable Deployment System (SEDS) concept. In this demonstration the tether will be cut and allowed to reenter the Earth's atmosphere after use. The proposed system will have a 10 km long tether which will be used to boost a 350 pound end mass about 70 km above the shuttle's orbit. The tether will be housed in a Get Away Special (GAS) can and the entire system will be mounted on a Mission Peculiar Experiment Support Structure as a partial payload.

SEDS will weigh approximately 450 pounds including the end mass. The diameter of the kevlar tether will be 1.65 mm. The concept consists of kevlar wound on a spool and placed in a GAS can. The tether will unwind from the outside surface of the spool. For control of the deployment speed, tension will be applied to the tether via gas bags located between the spool and the GAS can walls. A gas supply and metering system will be needed to maintain the proper pressure in the bags. The speed of deployment will be measured using an optical turn counter and a clock. A converging-shaped structural frame built above a GAS can will protect the tether and serve as an exit path for the tether. A cutting tool located at the top of the frame will sever the tether when the experiment is completed.

N88-10872

EXPERIMENTAL ASSEMBLY OF STRUCTURES IN EVA:
HARDWARE MORPHOLOGY AND DEVELOPMENT ISSUES

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Mary L. Bowden

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Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

presented at the

Space Construction Conference
NASA Langley Research Center
6-7 August 1986

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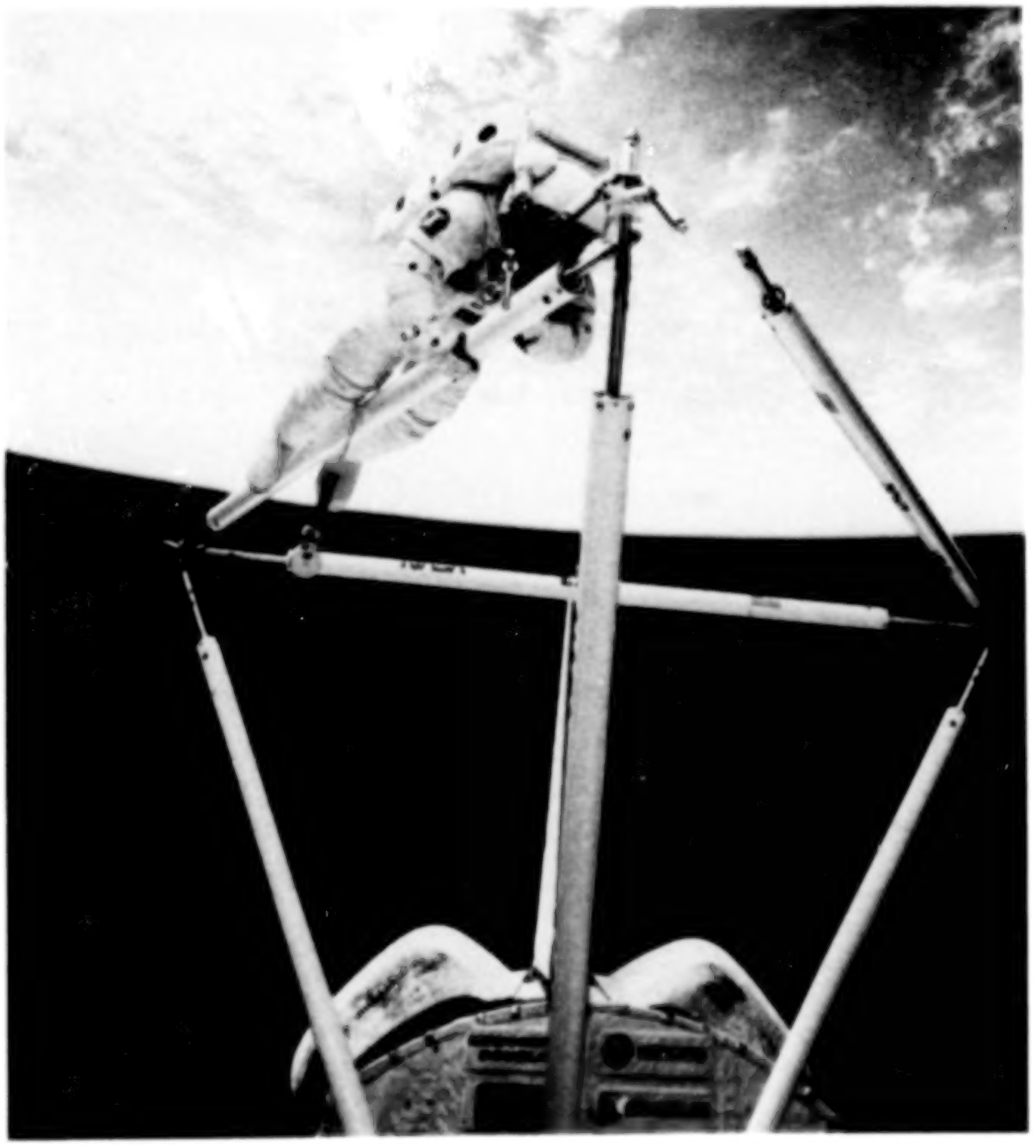
OVERVIEW

The MIT Space Systems Laboratory has been researching the human factors of space structural assembly since 1978. Previous systems studies of large space structures revealed that little was known about the productivity of humans in EVA structural assembly, despite its importance in overall systems optimization. A large body of data has been obtained by MIT during neutral buoyancy testing at the NASA Marshall Space Flight Center from 1980 to the present, and several conclusions were drawn. These efforts, and the most significant results therefrom, are summarized in this paper.

The EASE flight experiment was undertaken to validate these results on orbit, and to allow a quantitative comparison between orbital EVA and its neutral buoyancy simulation. Experiment hardware was designed and manufactured, and flown on STS 61-B in November 1985. This paper discusses the EASE experiment hardware, and illustrates how the experimental goals dictate its size, shape and operational characteristics.



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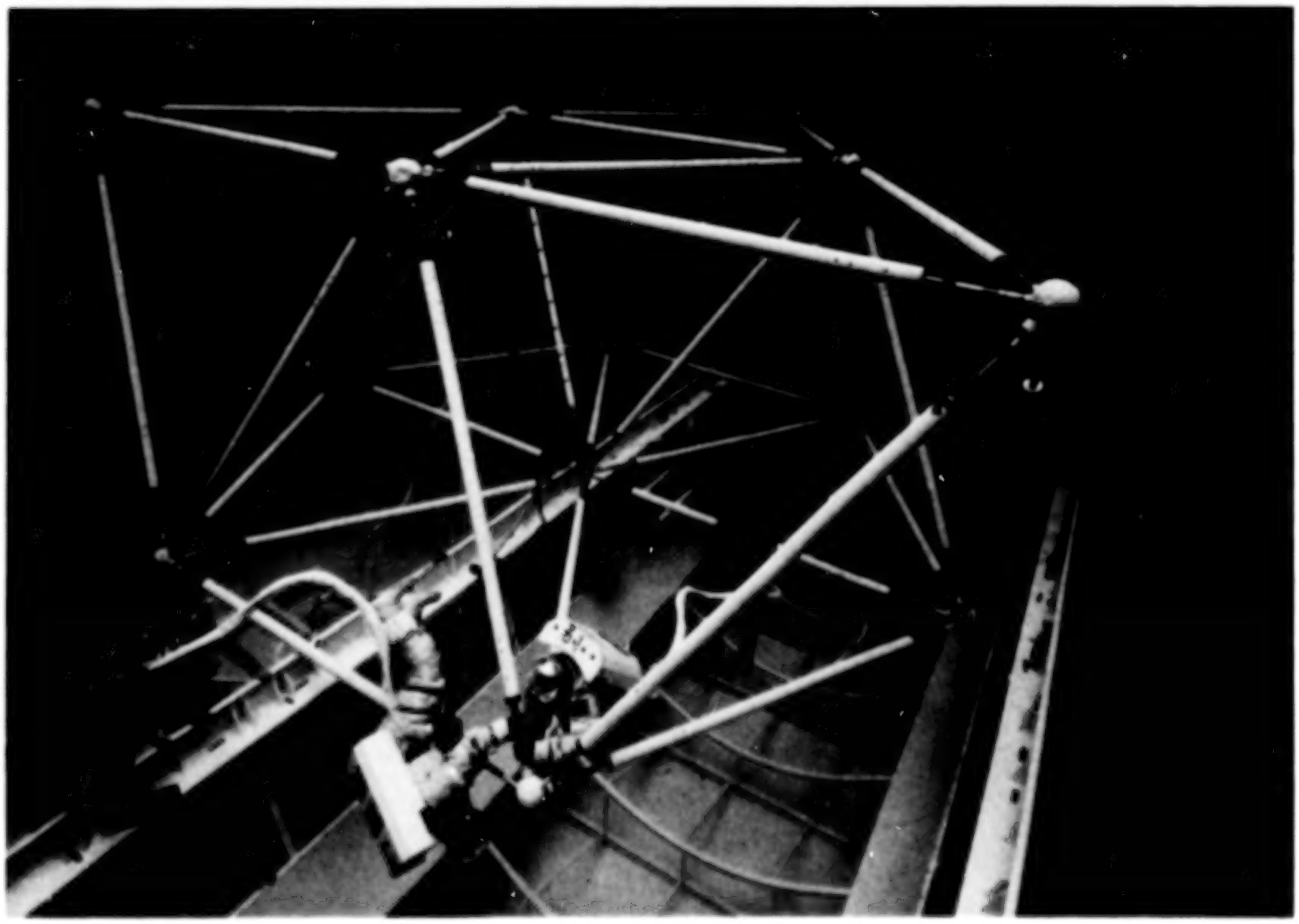
COMPLEX 36-ELEMENT TETRAHEDRAL TRUSS

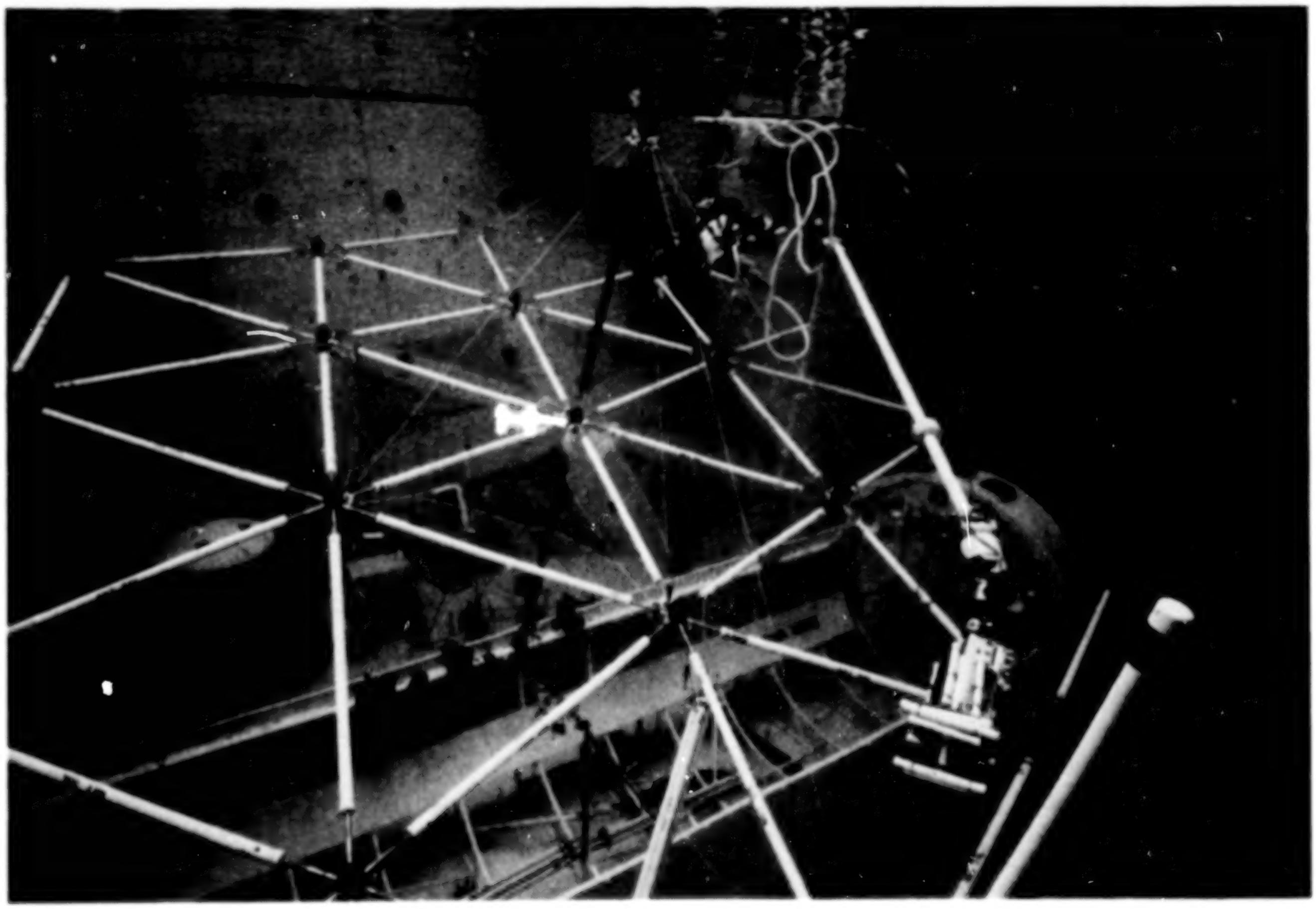
This structure consisted of 36 structural elements assembled to form a tetrahedral truss. This was used to obtain preliminary data on human productivity in weightlessness, on fatigue effects, and on teamwork for structural assembly. In addition, the worksite was set up so that the low man had foot restraints, while the high man performed his part of the assembly free-floating. The following results were obtained:

- People can be very productive in zero-g (approximately 600-700 kg/crewhour assembled).
- Fatigue could be a problem for extended EVA's.
- Teamwork should be kept flexible so that little time is spent waiting.
- While foot restraints are helpful, they are not essential for structural assembly.



ANTENNA STRUCTURE

This structure consisted of 44 structural elements arranged in a planar configuration to simulate an antenna-type structure. The real challenge of this construction was the installation of stiffening cables at all of the nodes of the structure. It was found that pressure suited subjects are perfectly capable of installing such cables, but it is time consuming and the cable cartridge mechanisms must be carefully designed for ease of operation.



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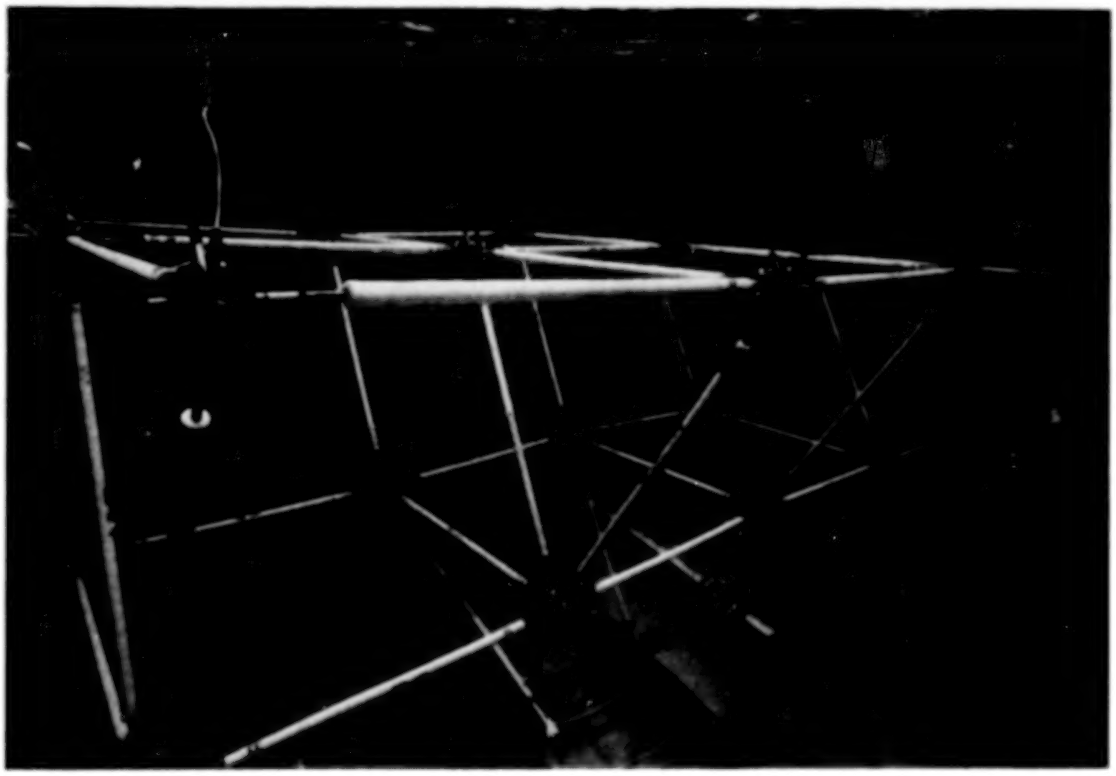
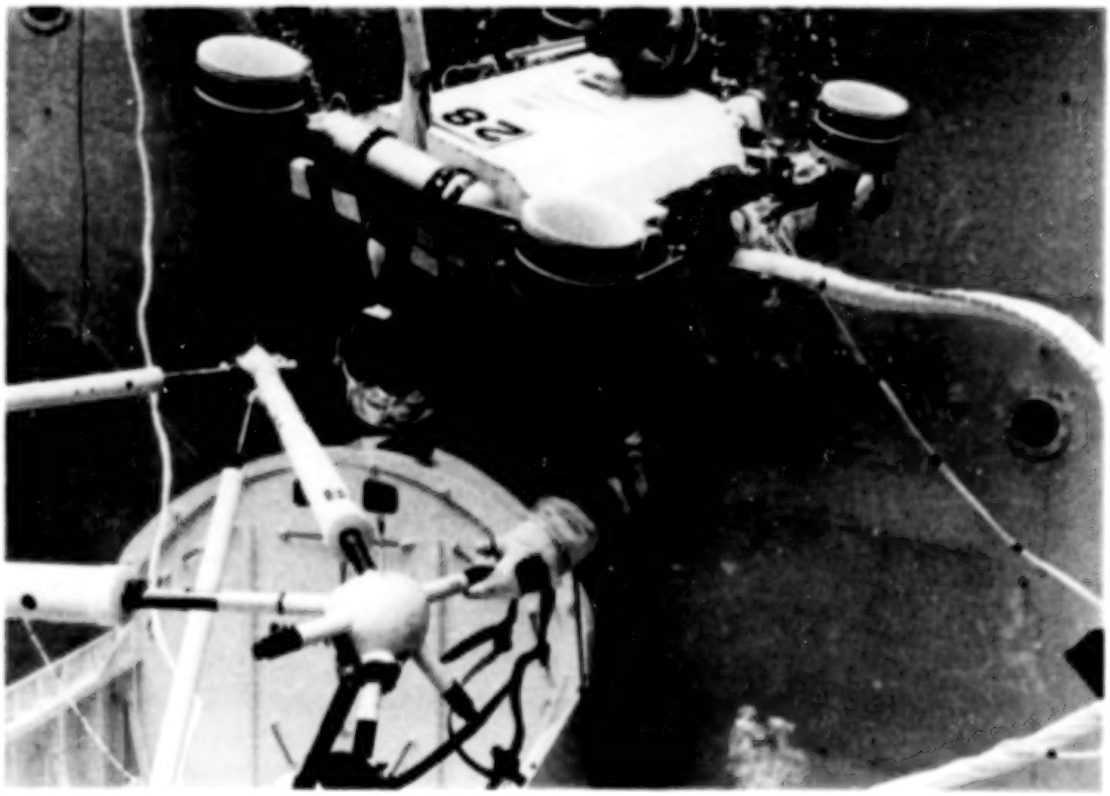
TRAPEZOIDAL TRUSS PLATFORM

This structure, consisting of 57 structural elements, was also used to test the ability of pressure-suited subjects to install cables as part of the assembly process. In addition, net sheets were installed on the structure to simulate reflective material that might be necessary on some space structures. Large equipment packages were also manipulated and mounted in this construction process in order to simulate activities that would be required to make a platform operational. All of these activities were found to be feasible, but the difficulty was very strongly dependent on the details of the particular simulation hardware.



PERSONAL UNDERWATER MANEUVERING APPARATUS

The Personal Underwater Maneuvering Apparatus (PUMA) was designed by the MIT Space Systems Lab to simulate the NASA Manned Maneuvering Unit (MMU) during neutral buoyancy tests. The PUMA was controlled by the subject using 2 hand controllers, one on each arm of the unit. One of the most important results was that for use during hardware manipulation (such as structural assembly), it was very helpful to have all controls located on the same side, so that the other hand could be free for carrying hardware. Overall, the PUMA was found to be very helpful for construction operations, primarily because it allowed maneuvers that otherwise would have been impossible if the subject were obliged to hold on to the structure at all times. However, it is not clear whether productivity is enhanced.



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SUMMARY OF EARLY NEUTRAL BUOYANCY RESULTS

The list of results shown below is a summary of neutral buoyancy results obtained by the MIT Space Systems Lab prior to the start of the EASE program.

Summary of Space Systems Laboratory Neutral Buoyancy Results

- Learning rates are higher in simulated weightlessness (60-70% vs 80% typical in similar 1-G tasks)
- Productivities average 600-700 kg assembled/crew hr in truss structure assembly
- Subjects manifest instinctive adaptations to the weightless environment given sufficient time (>15-20 hours) without foot restraints
- Questions unanswered by neutral buoyancy simulation:
    - How does crew performance in zero-G compare to that in neutral buoyancy?
    - Does underwater adaptation carry over to actual zero-G?
    - What physical workload is required to perform a strenuous task in EVA?
    - How do zero-G dynamics affect crew operations?
    - Are neutral buoyancy timelines accurate indicators of time for the same task in EVA?
    - Can a mathematical formulation of environmental dynamics be used to increase the fidelity of neutral buoyancy simulations?
    - What are the benefits and liabilities of restraint systems?

EXPERIMENT METHODOLOGY

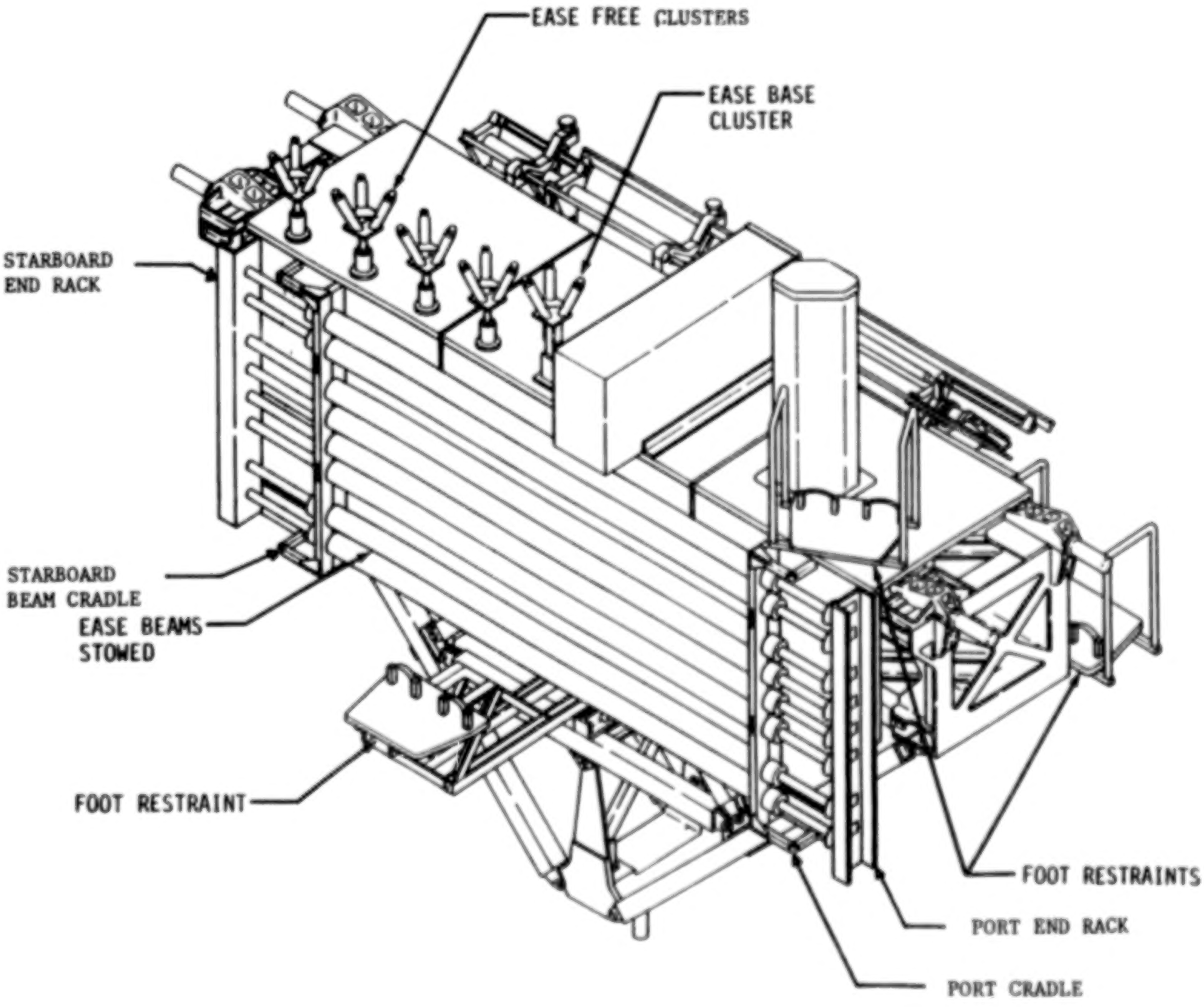
The design of the flight and training hardware was heavily influenced by the experiment methodology. The hardware was made as generic as possible so that the research results would be applicable to a wide class of space structures. Flight hardware was designed to have identical mass properties to the training hardware (since the flight hardware duplicated that used in previous neutral buoyancy research, flight hardware was designed to match their neutral buoyancy counterparts rather than vice versa). In order to minimize the required cargo bay volume, multiple repetitions of assembling a six-beam structure were accomplished rather than a single assembly of a larger structure. Data collection was limited to photographic sources, thus eliminating power and cooling requirements for the experiment hardware. Finally, a high degree of student involvement in hardware design and production was desired. This final requirement affected producibility of the hardware to the extent that moderate precision production methods were employed wherever high precision was not absolutely required. As an example, beams were assembled by match drilling parts in a jig, rather than manufacturing a full flight set of interchangeable beam components.

EXPERIMENTAL METHODOLOGY

- **Use generic structural hardware rather than mission-peculiar hardware**
- **Design flight hardware to have the same mass and moment of inertia as neutral buoyancy hardware**
- **Obtain data base by repetition of single cell assembly/disassembly, rather than flying multiple cell hardware**
- **Obtain body dynamics data by stereo imaging of worksite from aft flight deck windows**
- **Obtain task/timeline data by tracking EV subjects with shuttle CCTV system**

RESTRAINT HARDWARE

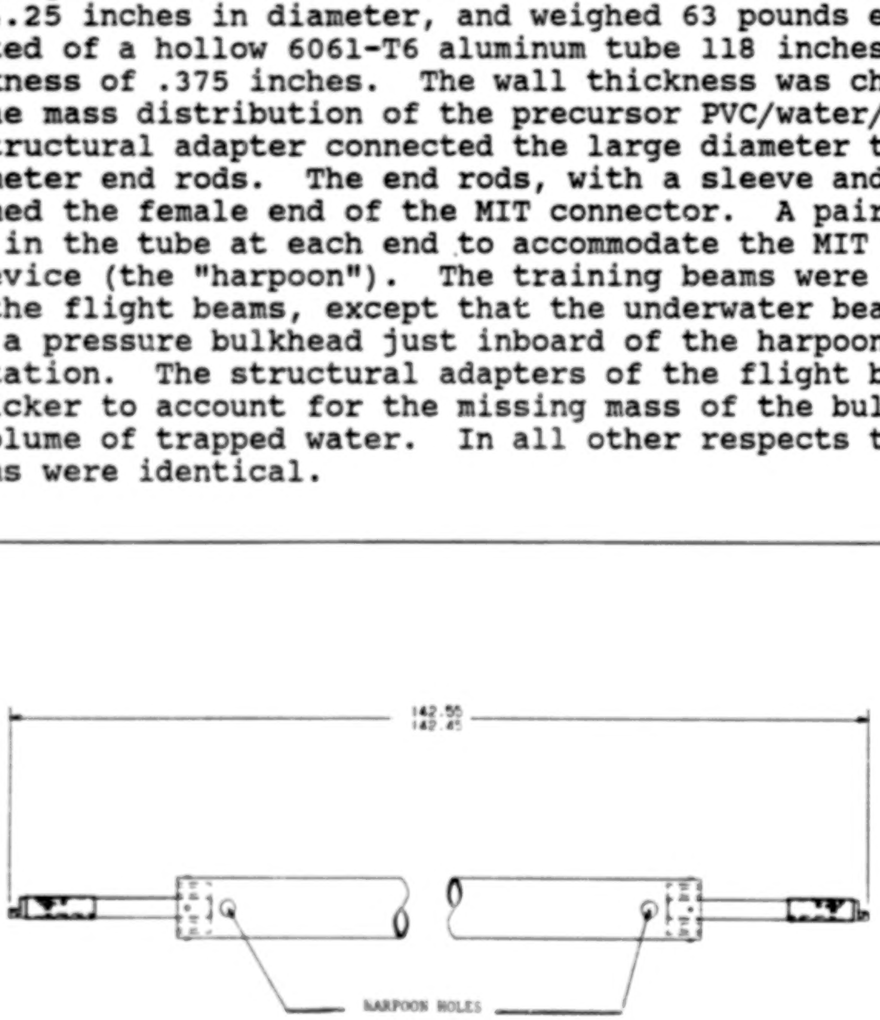
The EASE experiment hardware was mounted in the orbiter payload bay on the front surface of a Mission Peculiar Equipment Support Structure. This MPESS pallet, built by Teledyne Brown Engineering and supplied by NASA/MSFC, provided mounting points for experiment hardware to withstand launch and entry loads, and established the work stations for EVA operations. All experiment hardware had to be mounted to the MPESS pallet securely enough to withstand all design loading conditions, yet remain easily removable by the EVA crew for experimental activities. The beams were held in place for launch and landing by beam cradles and end racks. The cradles provided restraint in the orbiter X and Z directions, while the starboard end rack provided restraint in the Y direction. The port end rack was used to provide containment of loose beams, both as a redundant unit for launch and entry, and as the primary unit when the cradles were open during the experiment.



EASE/ACCESS FRONT VIEW CONFIGURATION

BEAMS

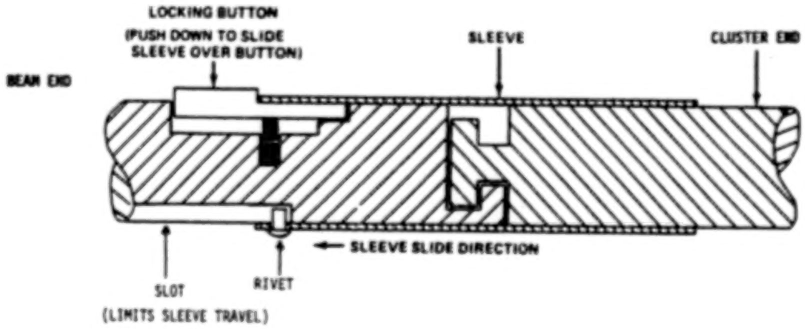
The beams used in the early MIT tests at MSFC consisted of ten-foot lengths of four-inch diameter PVC (polyvinyl chloride plastic) tubes filled with water. A smaller air-filled aluminum tube ran down the centerline of the beam to provide flotation. Joints were attached to the ends of the internal aluminum tube, resulting in overall beam lengths of 142.5 inches. The mass of each beam, including the trapped water inside the PVC tube, was approximately 63 pounds. Two new sets of beams were designed and built for the EASE experiment. One set was used for neutral buoyancy training, and the other set reserved for use in flight. Both sets of beams were 142.5 inches long (joint to joint), 4.25 inches in diameter, and weighed 63 pounds each. Each beam consisted of a hollow 6061-T6 aluminum tube 118 inches long with a wall thickness of .375 inches. The wall thickness was chosen to duplicate the mass distribution of the precursor PVC/water/aluminum beams. A structural adapter connected the large diameter tube to smaller diameter end rods. The end rods, with a sleeve and locking button, formed the female end of the MIT connector. A pair of holes was drilled in the tube at each end to accommodate the MIT temporary tethering device (the "harpoon"). The training beams were very similar to the flight beams, except that the underwater beams were sealed with a pressure bulkhead just inboard of the harpoon holes to provide flotation. The structural adapters of the flight beams were slightly thicker to account for the missing mass of the bulkhead and the small volume of trapped water. In all other respects the two sets of beams were identical.



BEAM

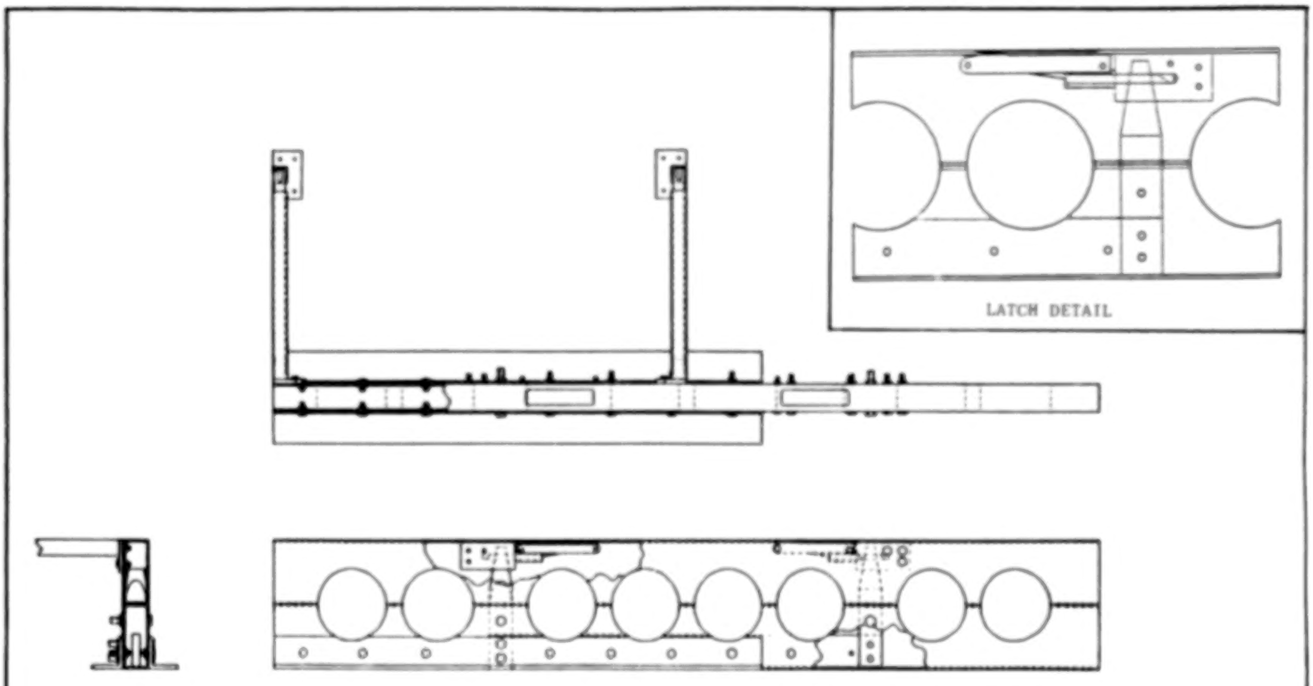
MIT STRUCTURAL CONNECTOR

The EASE joint configuration was chosen from among many designs during the early structural assembly tests performed at MIT. It is operated by placing the "mushroom" end in the matching receptacle and sliding the sleeve until the locking button pops up. Disassembly is effected by depressing the locking button, then sliding the sleeve over the button to expose the mushroom. It has several unique features which make it ideal for human factors research in space construction, though not necessarily suitable for future space structures. Foremost among these is the precise angular alignment required to slide the sleeve. Second is the unmistakable indication of a positive lock. Third is the side-entry configuration, which eliminates the requirement to deform the structure to insert the last beam. Fourth is the ease of disassembly. Last (but very important nonetheless) is its ease of construction from standard sized metal stock by students.



BEAM RESTRAINT CRADLES

The beam cradles were constructed from rectangular aluminum extrusion. Each cradle assembly consisted of two such pieces, attached edge to edge. One piece, called the fixed cradle, was bolted to flanges which were in turn bolted to the front face of the MPESS pallet. The other piece, called the restraint cradle, was mounted to a swing-arm assembly; this allowed the restraint cradle to be rotated outboard, out of the way for unobstructed access to the beams during assembly operations on-orbit. Each fixed cradle had two pylons, which mated to receptacles on the restraint cradles. The restraint cradles were equipped with flush-mounted shear pin latches to hold the cradles together during launch and entry.

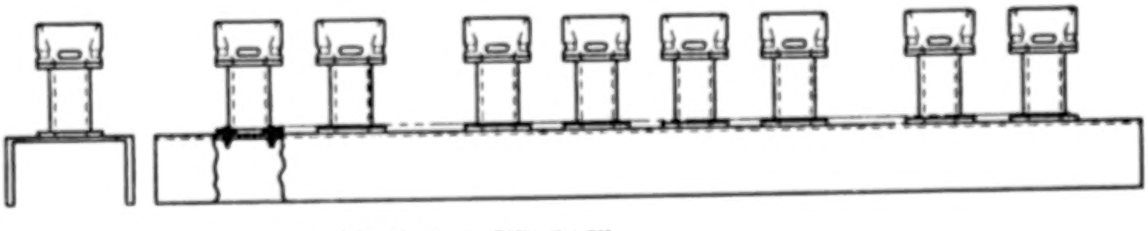


BEAM CRADLE (PORT SHOWN, STARBOARD OPPOSITE)

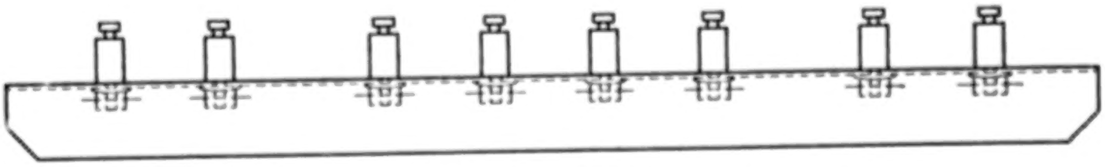
END RACKS

The end racks were constructed from aluminum channel stock. The starboard end rack was equipped with beam attach fittings, to which the beams were connected during launch and entry. The beam attach fitting was designed around the male end of the MIT connector, allowing the matching end of the beam to be used to secure the beam against Y-axis launch loads. The beam attach fittings were designed to float in the X and Z directions, while providing rigid restraint in the Y direction. This free play was an essential feature which served two purposes: decoupling end rack vibration from beam/cradle vibration, and providing tolerance for misalignment between the end racks and cradles. The port endrack was equipped with "beam cups," which were funnel-shaped fittings into which a beam end could be inserted with up to 20° of misalignment. The purpose of the cups was to restrain the port end of the beams when the cradles were open.

The beam restraint system also included a row of delrin clips near the starboard end rack. These clips were similar in size, shape, and function to broom clips found in household closets. The clips were used to restrain the starboard end of the beams when the cradles were open. The beam clips were easier to use for temporary beam restraint during EASE operations than the beam attach fittings, which were intended to be cycled only once during the course of the EASE experiment. The combination of the beam cups and the delrin clips allowed easy access and stowage of the beams from any position along the forward face of the MPESS pallet. The clips provided a retention force of approximately 20 pounds in room temperature ground-based tests. This retention force was sufficient to preclude equipment loss while not impeding access to the hardware.



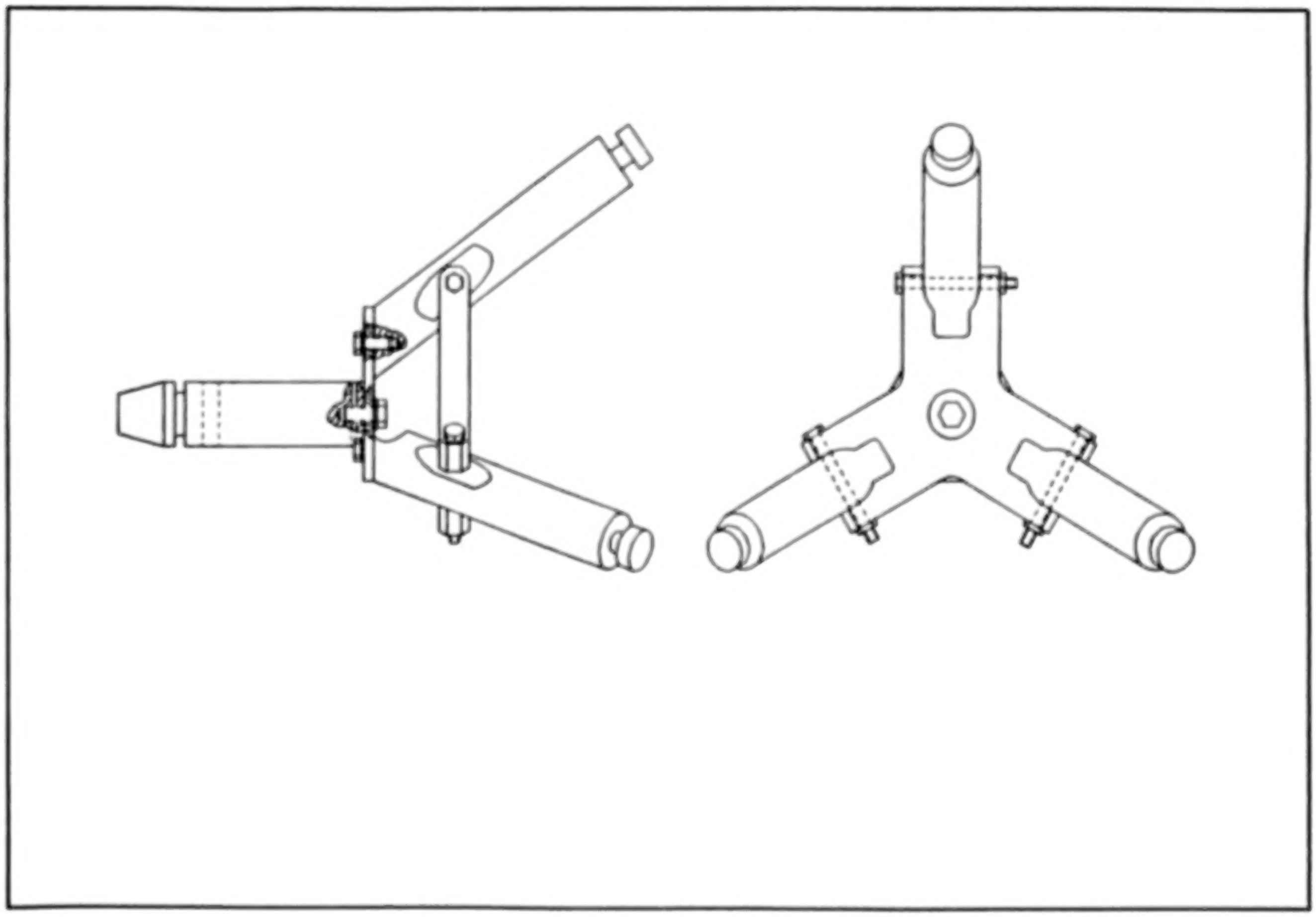
STARBOARD END RACK



PORT END RACK

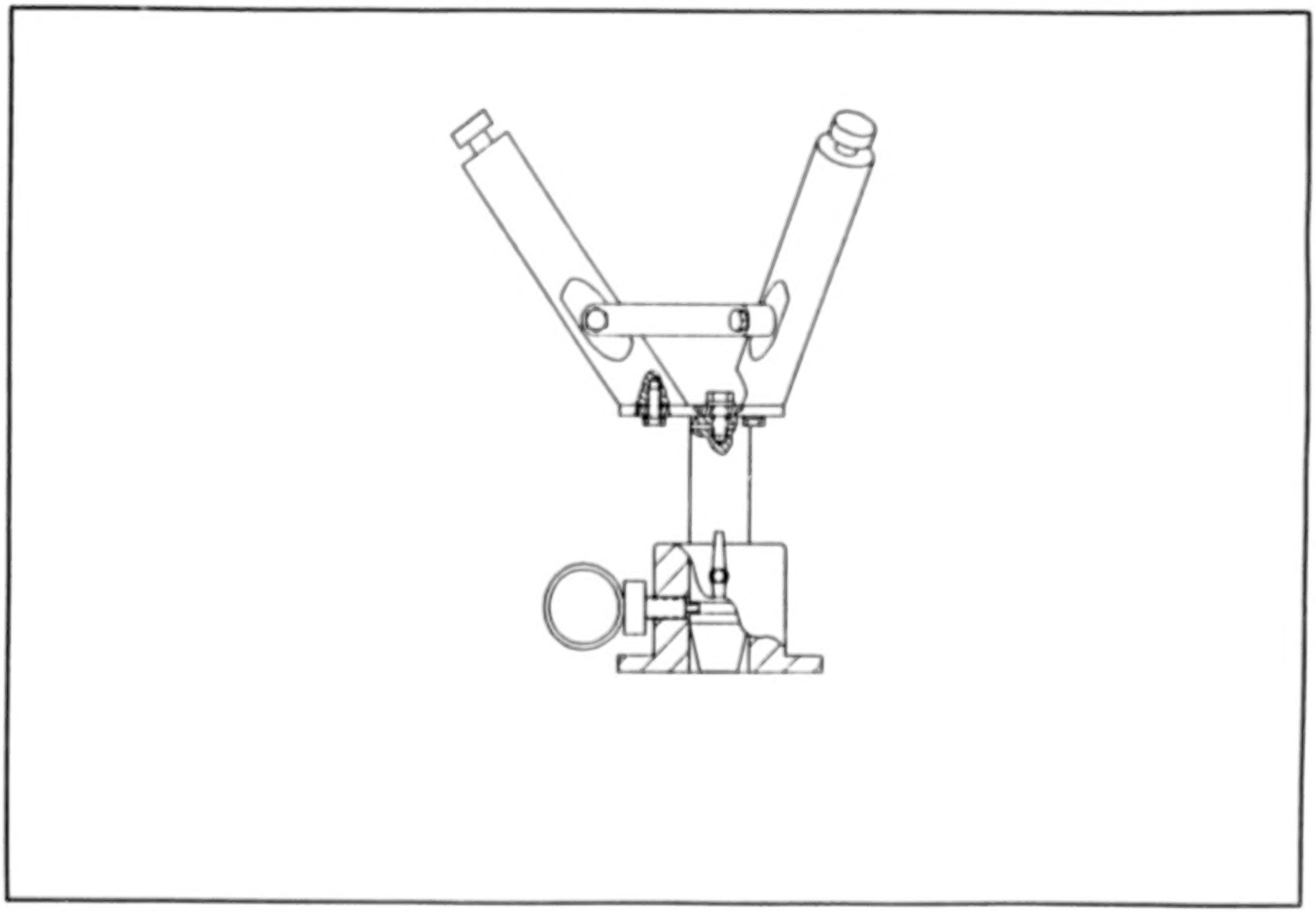
JOINT CLUSTERS

Each joint cluster contained three joint ends, held rigidly at the proper angles for attachment into the tetrahedron. The flight and neutral buoyancy clusters differed only by the use of flotation foam to make the underwater clusters neutrally buoyant. The EASE structure was built in the shape of an inverted tetrahedron, mounted to the flight support structure only at the single lower vertex. This "base" cluster was made to be kept fixed; the three "free" clusters were designed to be removed from their restraints to be mounted into the upper vertices of the structure.



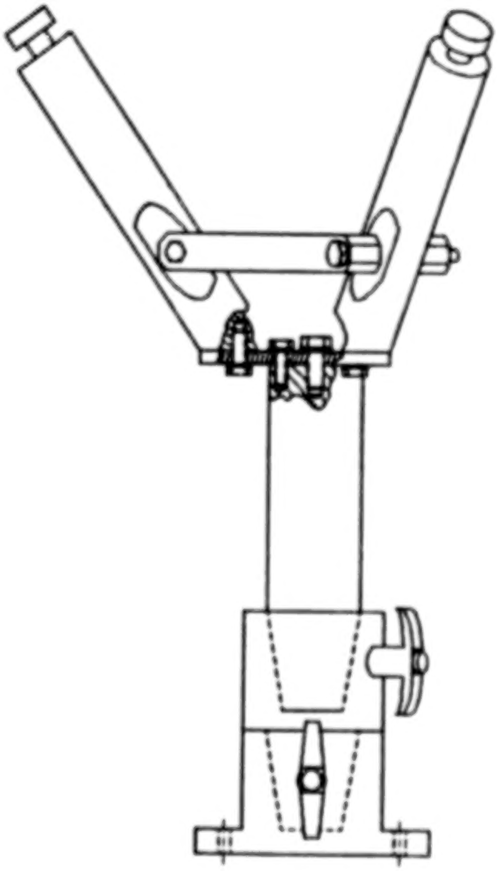
FREE CLUSTER STOWAGE

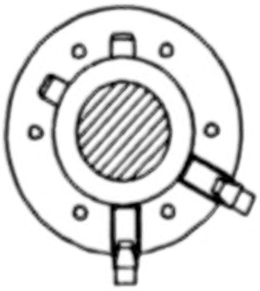
The launch restraint system for the free clusters consisted of a flanged receptacle with a pip pin, and a spring-loaded plunger. The pip pin, a locking pin controlled by a push-button on the end of the T-handled shaft, provided positive restraint for launch and reentry, and was removed during the experiment operation. The spring-loaded plunger, actuated with a 1.5 inch pull ring, was used to hold the cluster while the experiment was in progress. The cluster could be inserted into the receptacle with one hand; the plunger retracted as the tapered cluster handle was pushed past, then extended into an annular slot around the circumference of the handle as the cluster seated in the receptacle. Removing the cluster required two hands; one to pull the plunger back, and the other to pull out the cluster. This design was chosen to permit easy one-handed stowage, while precluding inadvertent release by kicking the cluster or snagging it with a tether.



BASE CLUSTER WITH JETTISON CAPABILITY

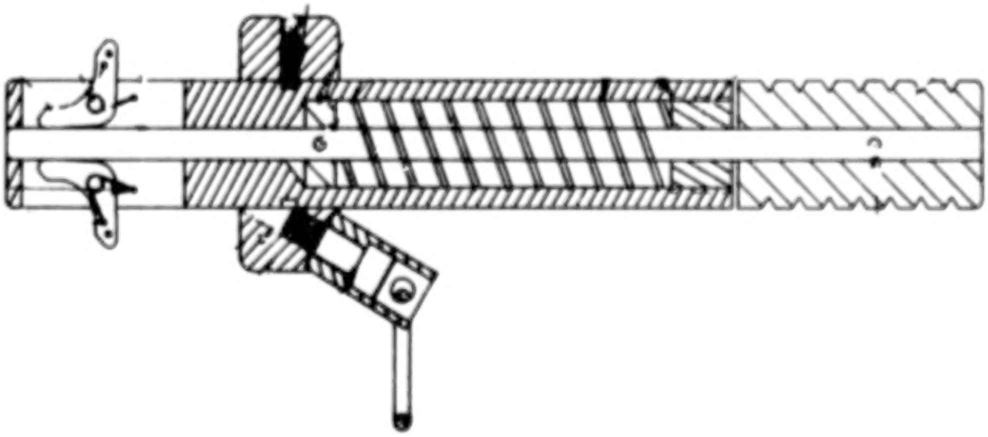
The base cluster was similar to the free clusters, except for its attachment to the MPESS pallet. Certain failure scenarios required the rapid jettison of a fully or partially assembled tetrahedron. Therefore, a design was chosen which incorporated a single-pin manual jettison capability. This jettison capability was duplicated to provide redundancy. Since the assembly loads were transmitted to the orbiter through the base cluster handle, a larger handle was used than those on the free clusters. For assembly loads, the junction between the base cluster and its handle was strengthened with a collar.





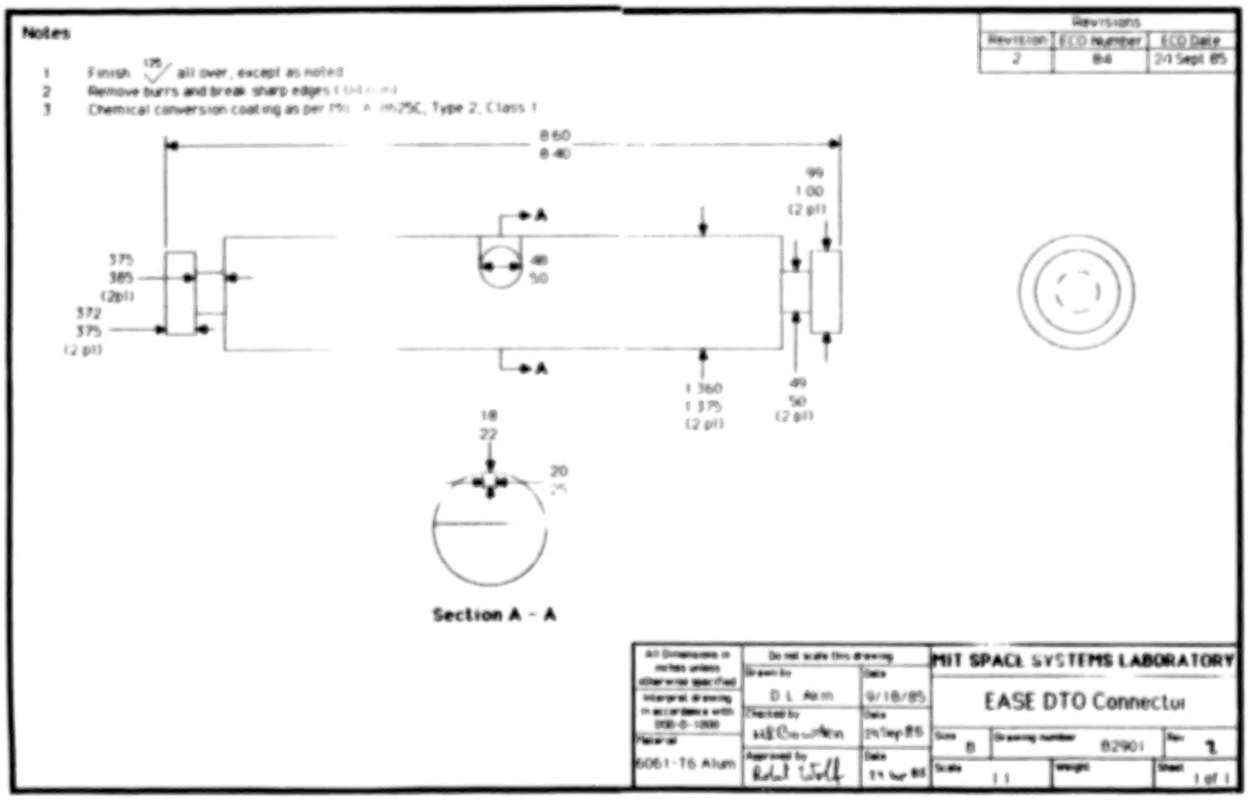
HARPOONS

An easy-actuating tethering device called a "harpoon" was used to facilitate tethering beams and clusters. The harpoon was originally developed in 1980 by MIT students for tethering hardware in neutral buoyancy, since the standard EVA tether hooks were too cumbersome for extended and repeated use. Two spring-loaded pins on one end of the cylindrical barrel were designed to pivot backwards, allowing the insertion of the pins through a 1.125 inch hole. Once inside, the pins return to their extended position, securing the piece of hardware. By grasping and pulling the handle of the harpoon, the pins are released to rotate forward, releasing the harpoon from the hole. The barrel of the harpoon incorporated a 1.5 inch ring for use with the EVA tethers. Originally made from plastic, the harpoons were redesigned for flight use by the substitution of aluminum for plastic, and the strengthening of the tether attach point. Four of the harpoons flown were intended to be used by the EVA crew, attached to standard wrist tethers. The fifth was permanently attached to a 35 ft wire cable with spring return, identical to those used on the port and starboard slide wires for crew restraint. This assembly, tethered to an fixture next to the base cluster, was used to keep the large beams under positive restraint while not attached to the structure or inserted in the beam cradles.



SPECIAL CONNECTOR

In support of Space Station Office objectives, there was a requirement to connect two EASE beams together in a straight line. It was felt that this configuration, 4.25 inches in diameter by 25 feet long and 125 pounds mass, was representative of heat pipes planned for incorporation into the space station thermal management system. To allow the EVA crew to manipulate such an assembly, a linear beam interconnect, known as the "EASE special connector", was designed and delivered. This simple device, machined from a single piece of aluminum, provided two male connector ends with a recessed hole for tethering purposes. The special connector and the five flight harpoons were launched in the provisional stowage assembly, and thus required no special launch restraint mechanisms.



N88-10873

ACCESS FLIGHT HARDWARE DESIGN AND DEVELOPMENT

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Space Construction Conference
NASA Langley Research Center
Hampton, Virginia
August 6-7, 1986

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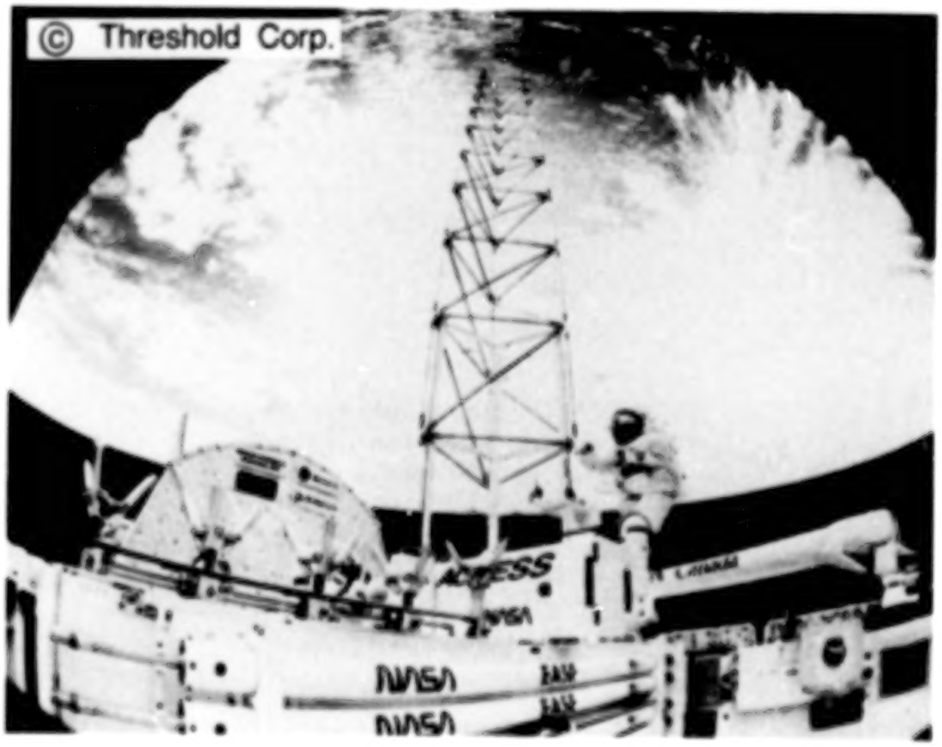
INTRODUCTION

The Assembly Concept for Construction of Erectable Space Structure (ACCESS) Flight Experiment was launched on STS 61B on November 26, 1985. It was the first NASA experiment to study orbital construction of a space truss by astronauts in extravehicular activity (EVA). The objectives of the experiment were to: (1) gain on-orbit construction experience, (2) correlate orbital assembly rates and assembly techniques with simulated zero-G ground tests, (3) identify construction procedure elements which will improve erectable structures productivity, reliability, and safety, and (4) evaluate Space Station assembly and maintenance concepts and techniques. In order to meet these objectives, the experiment was composed of two parts. The first part (baseline experiment) was performed during the first EVA period. It consisted of assembling/disassembling a ten bay, 45-foot long truss structure utilizing two astronauts in fixed foot restraints located in the Orbiter payload bay. The second part (expanded experiment) utilized the Remote Manipulator System (RMS) and the Manipulator Foot Restraint (MFR) to provide a mobile work station for an astronaut. This system, including the baseline hardware, was used to evaluate/demonstrate EVA structural assembly, structural repair, flexible utility cable installation, and large structural manipulation during the second EVA period.



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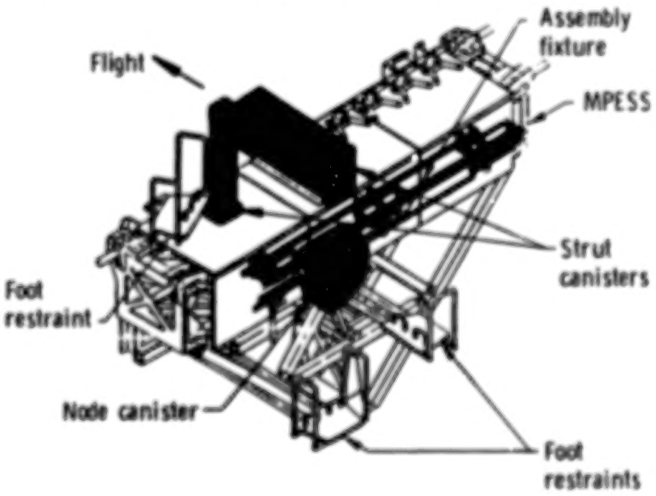
EXPERIMENT HARDWARE DESCRIPTION

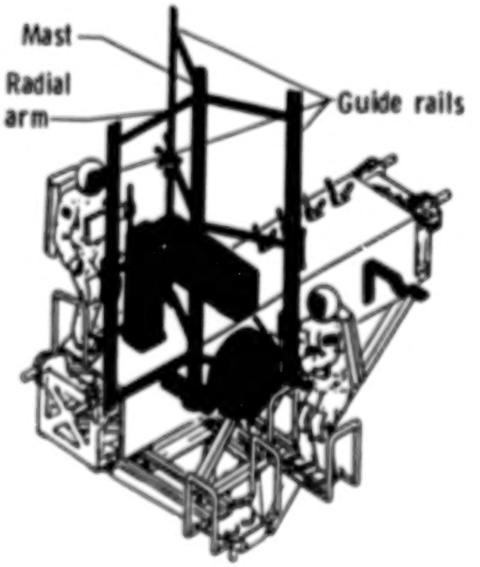
Before describing the hardware, it is important to note some preliminary factors which governed the design of the hardware. The first is that the hardware had to be designed to mount to the Multiple Purpose Experiment Support Structure (MPESS) Pallet utilizing one-half of the top and one side of the Pallet. Within this space, the Experiment had to be stowed, deployed, functioned, and restowed and not interfere with the Experimental Assembly of Structures in EVA (EASE) Experiment. Also the hardware was constrained to be of relatively low cost, completely mechanical, EVA friendly, and capable of being developed in a short time frame.

The ACCESS hardware consists of an assembly fixture, a diagonal strut canister, a batten/longeron strut canister, a node canister, and the truss structure components which are stowed in these canisters. The assembly fixture is rotated from the stowed position to the vertical position (STS Z-axis) and then the guide rails are unfolded to place the assembly fixture in the deployed configuration. The latches on the strut canister doors are disengaged and the doors are rotated to the open position. The spring loaded pin and the backup quick-release pin are retracted on the node canister and the node canister is rotated to an open position. At this point the nodes and struts are removed from the canisters and installed on the assembly fixture to form the truss structure.

ACCESS EXPERIMENT IN STOWED CONFIGURATION

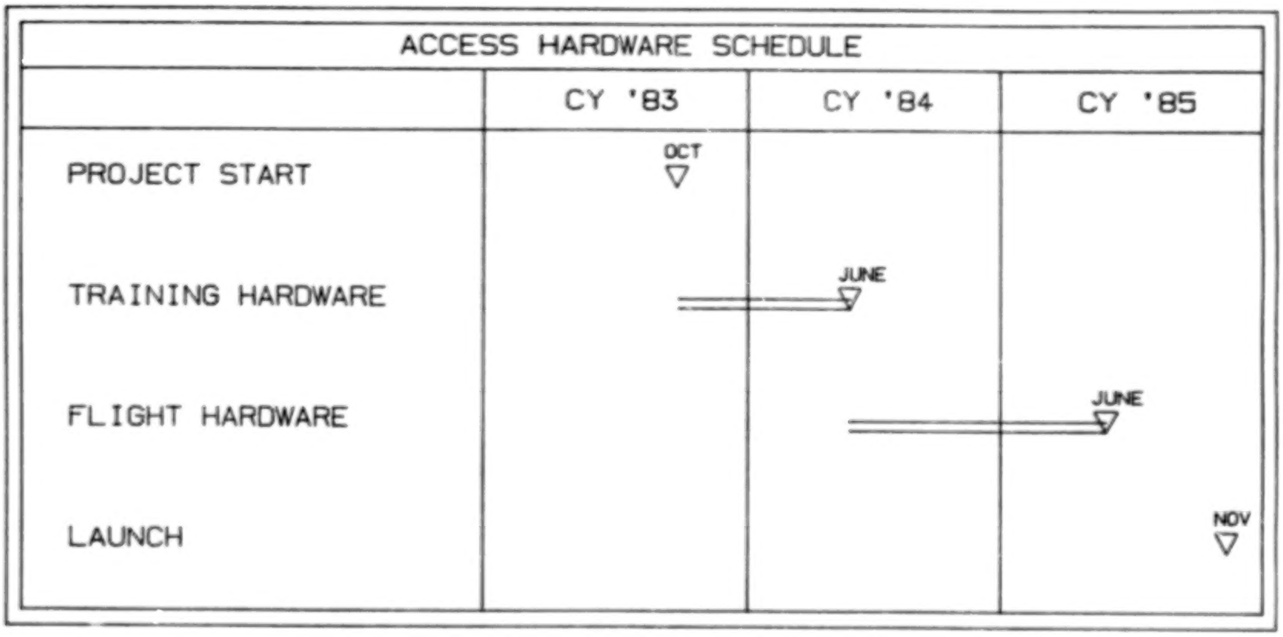


DEPLOYED ASSEMBLY FIXTURE



DESIGN REQUIREMENTS - SCHEDULE

The ACCESS experiment was a payload of opportunity and as such was developed on an accelerated schedule in order to maximize the opportunities for flight. Two sets of hardware were fabricated; the training hardware was delivered eight months after the project's starting date with the flight hardware following twelve months later. Developing the hardware on such an ambitious schedule created immense pressure on all aspects of the project including the design, analyses, fabrication, procurement, testing, and integration.



DESIGN REQUIREMENTS - LOADS

Design loads were developed for the experiment stowed configuration utilizing the STS induced environments. The random load factor (RLF) for in-plane loads was defined to be equal to three times the input GRMS level. For out-of-plane loads, the RLF was determined from the following relationship: $RLF = 3\,[\pi/2 \cdot Q \cdot Fn \cdot PSD]^{1/2}$ where Q equals the component amplification factor, Fn equals the component natural frequency, and PSD equals the power spectral density of the input spectrum at Fn. Three load cases were considered which combined the quasi-static load for all three axes plus the random load factor for each axis respectively. The worst case of these loads was used in the design analysis.

DESIGN LOAD FACTORS FOR LAUNCH

AXIS	QUASI-STATIC LOAD FACTOR (G's)	RANDOM LOAD FACTOR (G's)			
		ASS'Y FIX	BATT./LONG. CANISTER	DIAGONAL CANISTER	NODE CANISTER
X	4.8	3.2	11.9	11.9	16.9
Y	2.7	11.9	11.9	11.9	17.0
Z	5.9	3.2	15.3	16.0	17.0

DESIGN LOAD FACTORS FOR LANDING

AXIS	QUASI-STATIC LOAD FACTOR (G's)
X	6.6
Y	3.0
Z	8.0

DESIGN REQUIREMENTS - STRUCTURAL/DYNAMIC ANALYSES

Finite element models of both the experiment stowed and deployed configurations were developed. These models were integrated into STS system models and used to determine coupled loads and frequency response data when subjected to the STS lift-off/landing and on-orbit environments. These data were used to verify the following structural requirements:

Factor of safety (yield) = 1.25
Factor of safety (ultimate) = 2.0
Component stowed configuration Fn >35 Hz
Experiment deployed configuration Fn > .3 Hz

All of these requirements were satisfied with the exception of the assembly fixture which had a first mode frequency of 32 Hz in the Z-axis. This required that a finite element model of the assembly fixture be generated and integrated into a model of the Multiple Purpose Experiment Support Structure (MPESS). This systems model was used to determine the degree of coupling between these structures when subjected to the simulated STS lift-off and landing environments. These new loads were found to be within the design limits of the hardware.

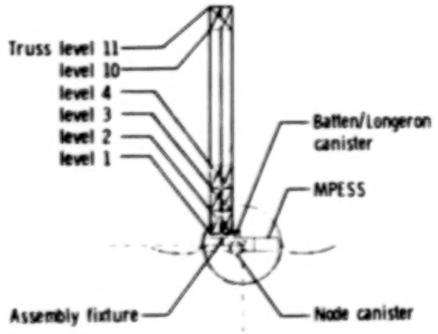
ANALYSIS RESULTS

STOWED CONFIGURATION	FN (HZ)	FACTOR OF SAFETY
DIAGONAL STRUT CANISTER	100	2.06
BATTEN/LONGERON CANISTER	110	2.02
NODE CANISTER	70	2.74
ASSEMBLY FIXTURE	32	2.12
DEPLOYED CONFIGURATION		
TRUSS STRUCTURE-ASSEMBLY FIXTURE	.569	4.08

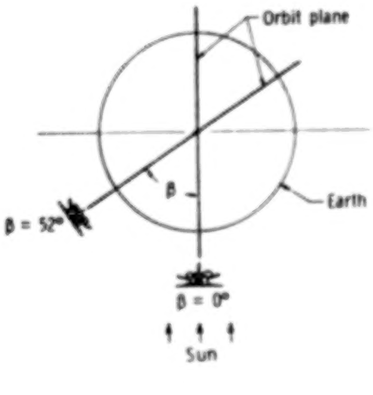
DESIGN REQUIREMENTS - ENVIRONMENT

The experiment hardware had to be capable of functioning in a hard vacuum and within prescribed temperature limits. The temperature limits were developed from the materials capability, the extravehicular mobility unit (EMU) glove interface limits (235°F to -180°F) ref. 1, and the allowable thermal gradients between the individual truss components and between the truss structure and the assembly fixture (ref. 2).

ACCESS THERMAL MODEL



ORBIT ANGLE DEFINITION



ANALYSIS RESULTS

(Bay-to-Earth Attitude)

	Temperatures, °F					
	β = 0°		β = 52°		β = 80°	
	Max	Min	Max	Min	Max	Min
MPESS	+ 2	− 11	− 2	− 13	+ 4	− 12
Batten/Longeron canister	+ 3	− 24	− 1	− 21	+ 25	− 2
Diagonal canister	+ 1	− 21	+ 12	− 9	+ 7	+ 24
Node canister	+ 1	− 2	− 4	− 5	− 7	− 7
Mast	− 7	− 15	+ 5	+ 1	+ 19	+ 19
Assembly fixture	− 6	− 20	+ 8	− 12	+ 40	+ 4
Truss (initial)	− 11	− 11	− 8	− 8	+ 14	+ 14

DESIGN REQUIREMENTS - MATERIALS

Metallic materials were screened to insure compliance with the stress corrosion cracking criteria as specified in reference 3.

Non-metallic materials were screened to insure compliance with the outgassing criteria as specified in reference 4 and 5.

MATERIALS

ASSEMBLY FIXTURE

6061-T6 AL
A286 ss
347 ss
RULON LD
300- SERIES ss
PH 15-7 ss
COHRLASTIC - R10470
 (SILICONE RUBBER)
RTV 511
RTV 560
SYNERGISTIC COATING
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT

BATTEN-LONGERON CANISTER

6061-T6 AL
300-SERIES ss
COHRLASTIC-R10470
 (SILICONE RUBBER)
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT
RTV 560

DIAGONAL CANISTER

6061-T6 AL
300-SERIES ss
COHRLASTIC-R10470
 (SILICONE RUBBER)
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT
RTV 560

NODE CANISTER

6061-T6 AL
A286 ss
347 ss
RULON A
6061-T651 AL
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT

TRUSS HARDWARE

6061-T6 AL
300-SERIES ss
7075-T73 AL
KAPTON
SYNERGISTIC COATING

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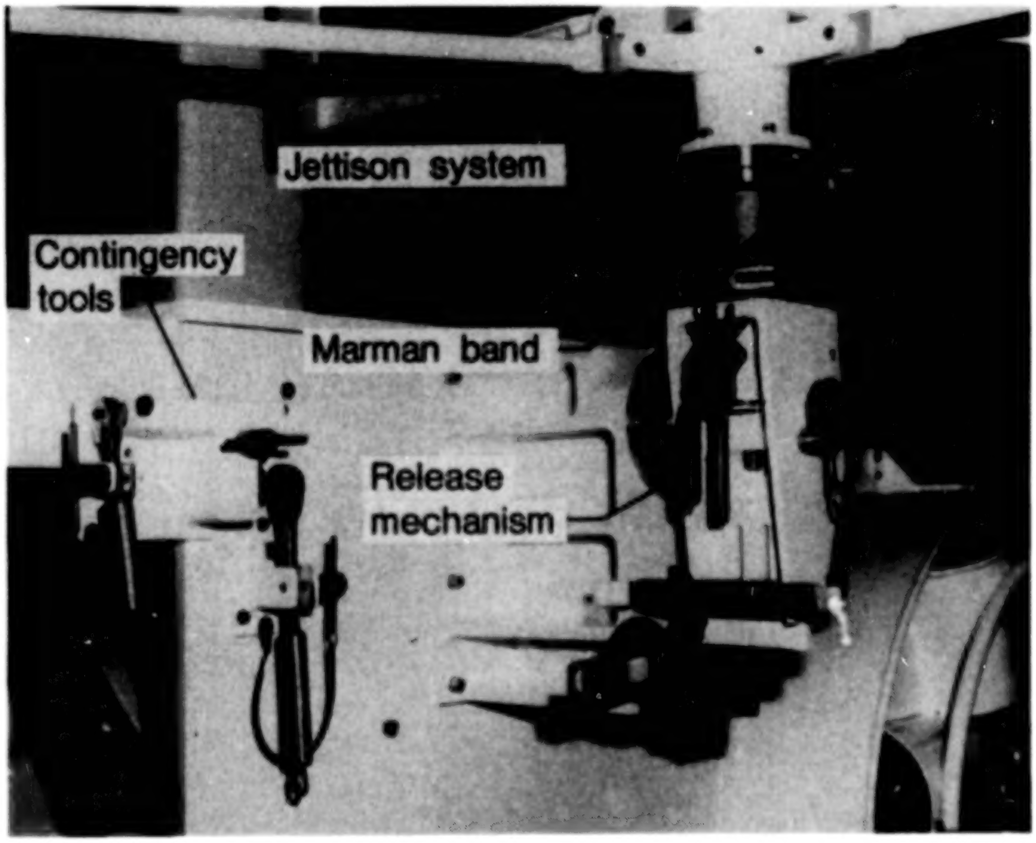
DESIGN REQUIREMENTS - SAFETY

Since the experiment violated the payload bay door envelope when erected, the hazard of being unable to close the doors had to be controlled by independent primary and backup methods, and this combination had to be two failure tolerant (ref. 6). The primary method of controlling the hazard was to disassemble the truss structure and restow the assembly fixture. The backup method involved jettisioning the hardware. This was accomplished through the manual release of an over-center latch on a marman band, retracting two quick-release pins, and squeezing a release mechanism which retracted a third pin. This allowed all of the hardware above the marman band interface to separate from the support structure. In order to provide redundancy in the jettison system, a second over-center latch was provided on the marman band. Also, the hardware could be jettisoned by using the contingency tools to remove four bolts and one nut and manually removing the assembly fixture from its support base.



DESIGN REQUIREMENTS - EVA COMPATIBILITY

The hardware was designed to interface safely and efficiently with the EVA crewmen. To insure that all of the requirements were identified and properly included in the design, reference 1, 7, and 8 were used along with actively involving the crew systems/astronaut personnel in the design, functional testing, and design review process.

EVA COMPATIBILITY REQUIREMENTS

- SHARP EDGE RESTRICTIONS (.04 MIN. RAD.)
- TOUCH TEMPERATURE LIMITATIONS
- CREW INPUT FORCES $\leq$ 25 LBS.
- AVOID HIGHLY REFLECTIVE SURFACES (SUN GLARE)
- LIMIT CREW HAND INTENSIVE FUNCTIONS
- MINIMIZE GLOVE WEAR

DESIGN REQUIREMENTS - FACTURE CONTROL

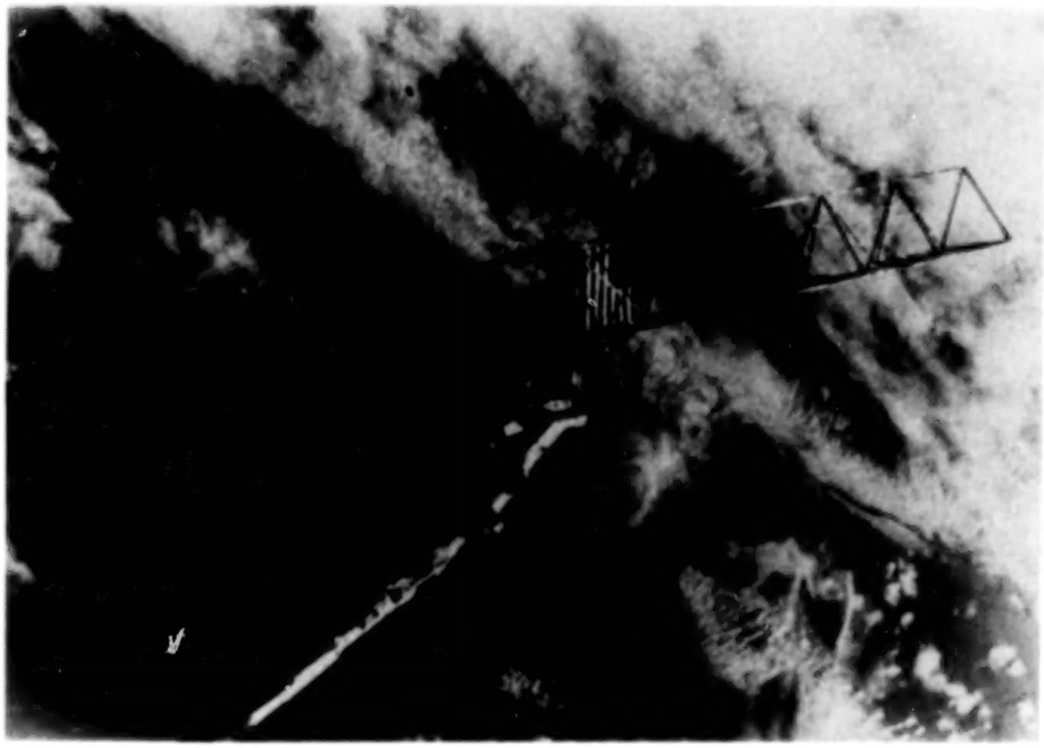
The fracture control requirements were satisfied by designing to the fail safe or safe life criteria as specified in reference 10. The fail safe criteria includes all parts which could completely fracture and not cause loss of life or loss of the Orbiter. Parts which can be classified as fail safe must satisfy one of the three following criteria. The first is that adequate multiple load paths exist which means that after the part has failed the loads can be redistributed through the remaining members with positive margins of safety. The second criteria is that if the part fails it would be contained. The third criteria requires that the part has a mass of .03 lbs or less. The safe life criteria requires that the part has the flaw growth capability to withstand four times the mission life without failure.

ANALYSIS RESULTS

COMPONENT	FRACTURE LIFE (CYCLES)	FACTOR OF SAFETY	A	2C
DIAGONAL STRUT CANISTER	265,000	5.7	.075	.150
BATTEN/LONGERON CANISTER	200,000	4.6	.075	.150
NODE CANISTER	310,000	6.1	.075	.150
ASSEMBLY FIXTURE	150,00	6.3	.075	.150

HARDWARE DESCRIPTION - TRUSS STRUCTURE

The truss hardware consists of 33 battens (horizontal strut members), 30 longerons (vertical strut members), 30 diagonal struts, and 33 nodes. The struts are fabricated from 1.0-inch diameter by .058-inch wall thickness 6061-T6 aluminum tubing and are insulated with .001-inch thick Kapton aluminized on one side. The batten and longeron struts are 3.95 feet long and the diagonal struts are 5.81 ft. long. The struts have quick-disconnect joints attached at each end to provide for easy attachment and removal of the strut to the node. The node consist of five parts fabricated from 7075-T73 aluminum. The guide part of the node slides on a 0.500-inch dia. stainless steel rod attached to the end of the guide rails on the assembly fixture. The guides as well as the stainless steel rods are coated with a synergistic coating process in order to minimize the frictional forces developed when the truss structure slides on the assembly fixture. These components are stowed in canisters for containment during the lift-off and landing phases of the flight and are individually removed on-orbit for assembly of the truss structure.



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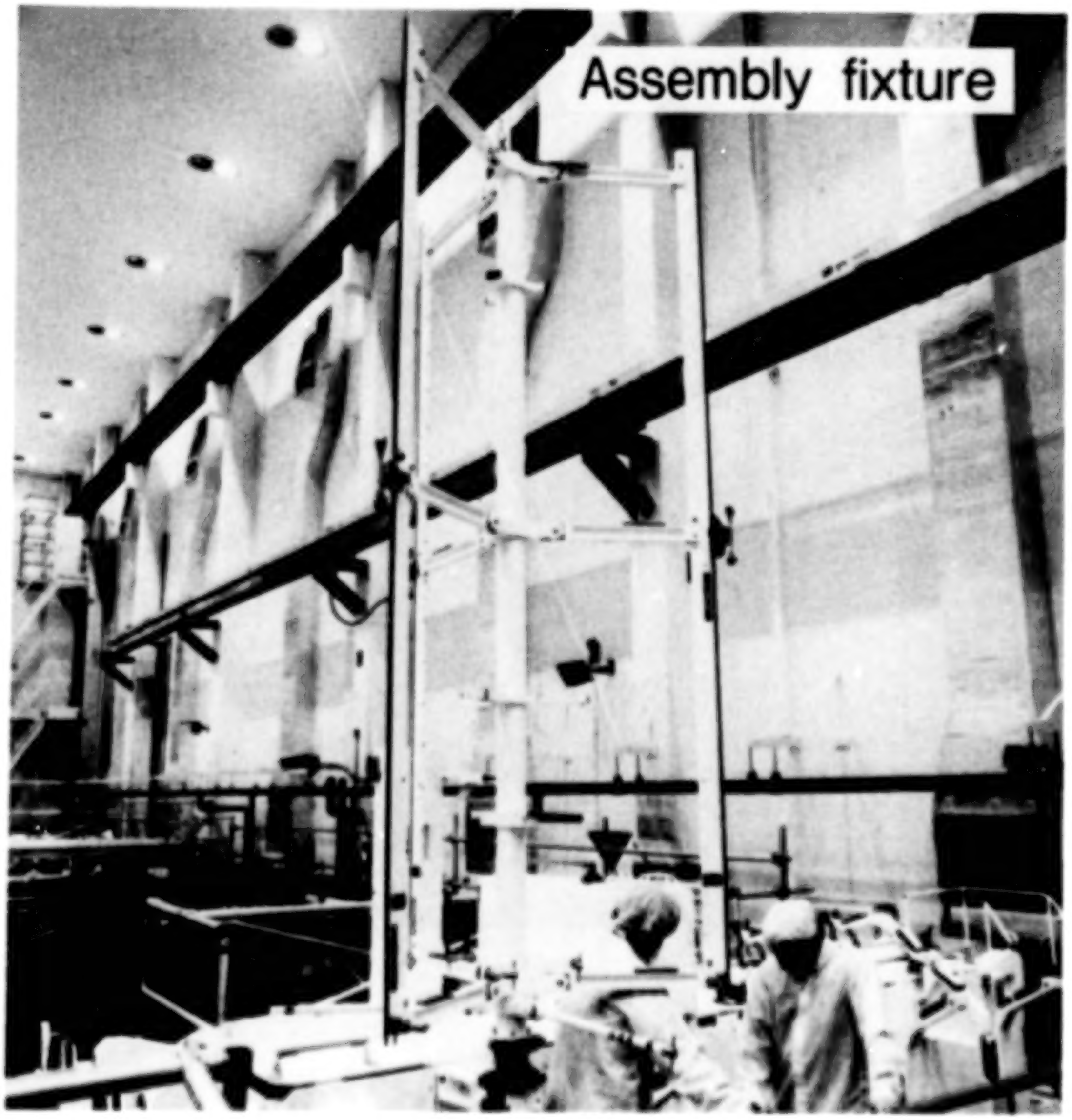
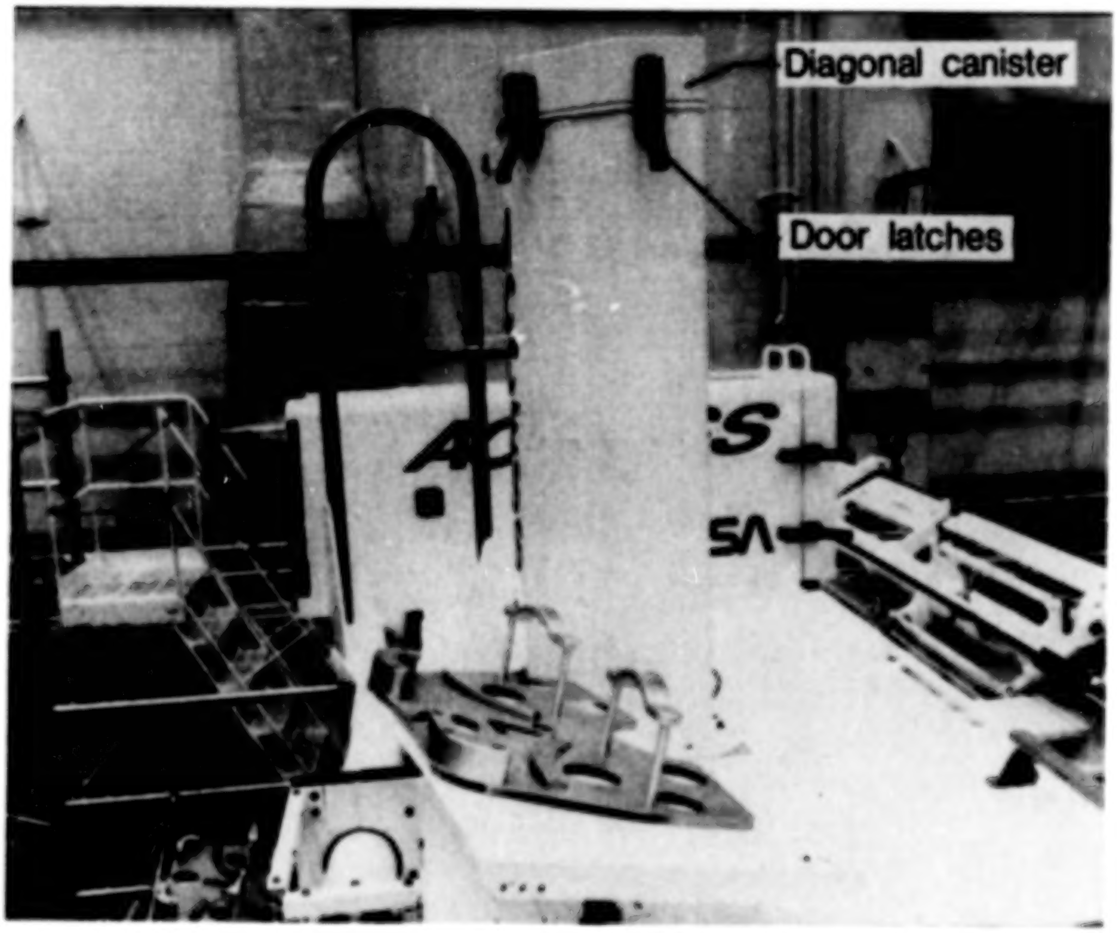
HARDWARE DESCRIPTION - ASSEMBLY FIXTURE

The assembly fixture consists of a 4.0-inch diameter aluminum core tube with three guide rail assemblies which are stowed next to the core tube for lift-off and landing. The core tube and guide rails are attached to the MPESS pallet through a bracket at the base of the core tube and two mast clamps. Once in orbit, the mast clamps are manually opened and the assembly fixture is rotated to the vertical position (STS Z-axis) and the guide rail assemblies are deployed. This system rotates about the centerline of the core tube providing a moving structure on which to assemble the truss structure. The assembly fixture is two bays long providing room for the assembly of one bay and structural support for the bay of truss structure immediately above the assembly area.



HARDWARE DESCRIPTION - DIAGONAL CANISTER

The diagonal strut canister is an irregular shaped 6.0-ft. long canister which houses 3 battens and 30 diagonal struts. The canister is mounted on the top surface of the MPESS pallet with 2.6 ft. protruding through the top surface into the inside of the pallet geometry. The canisters consist of 5 baffle plates, 33 thin-wall aluminum guides tubes running the entire length of the canister, a 0.06-inch thick aluminum skin forming the exterior surface, and a door with redundant latches to contain the struts. The struts are stowed in the canister with a 1.5-inch stagger between rows to allow for unaided removal of the struts from the canister by the space suited astronaut. Spring clips are installed in each guide tube to prevent the struts from accidentally floating out of the canister once the door is opened.



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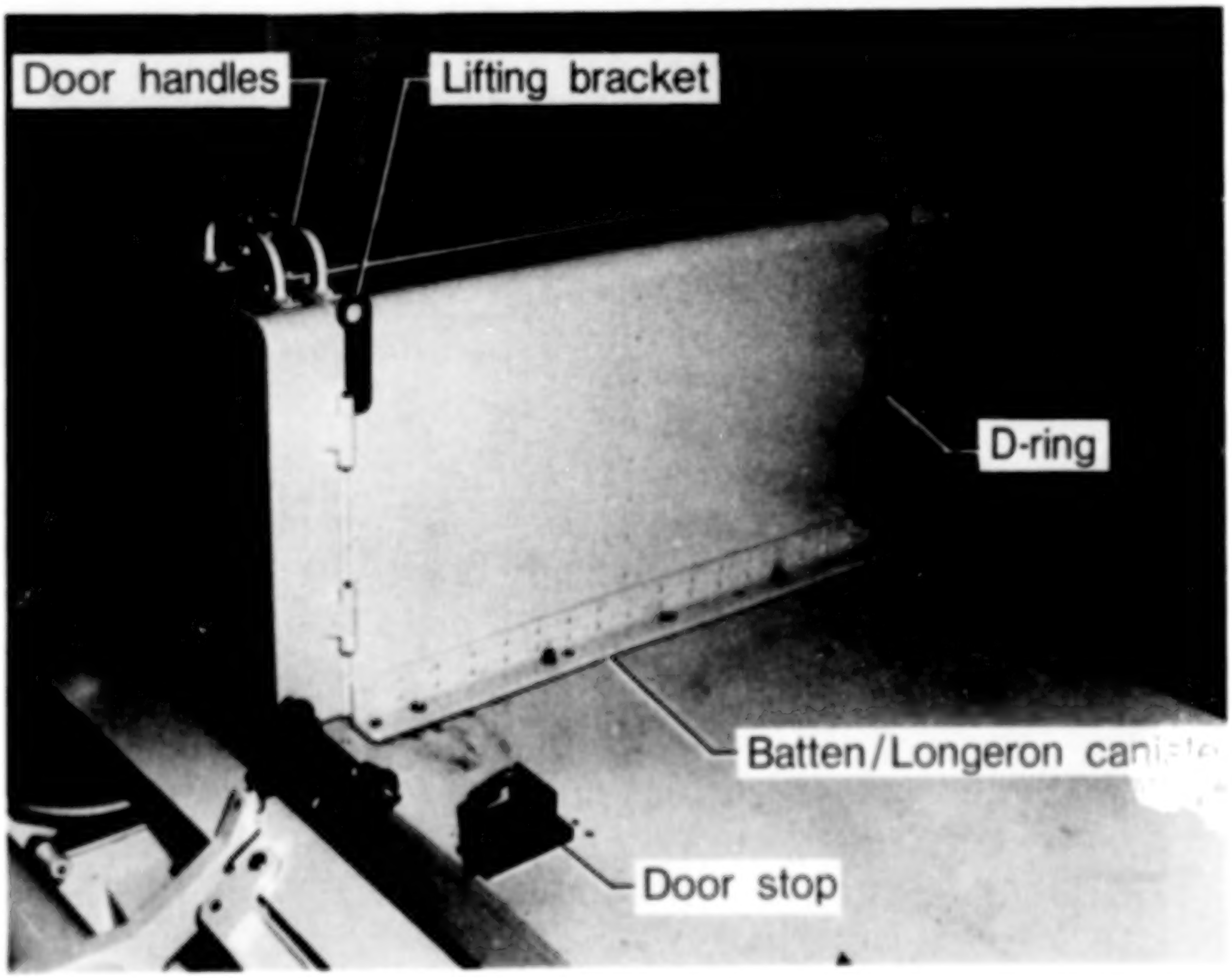
HARDWARE DESCRIPTION-BATTEN/LONGERON STRUT CANISTER

The batten/longeron canister is 1.0 by 1.5 by 4.1 feet long and houses 60 batten/longeron struts. It is mounted on the top surface of the MPESS pallet facing aft in the STS cargo bay. The batten/longeron canister design is identical in concept to that of the diagonal canister. The "D" ring brackets are mounted on both sides of the canister to provide an attachment point for the payload retention device (PRD). The PRD would be used to hold the door closed for reentry in case the canister latches failed on-orbit. The door stop bracket is used to hold the door open during the removal and stowage of the struts.



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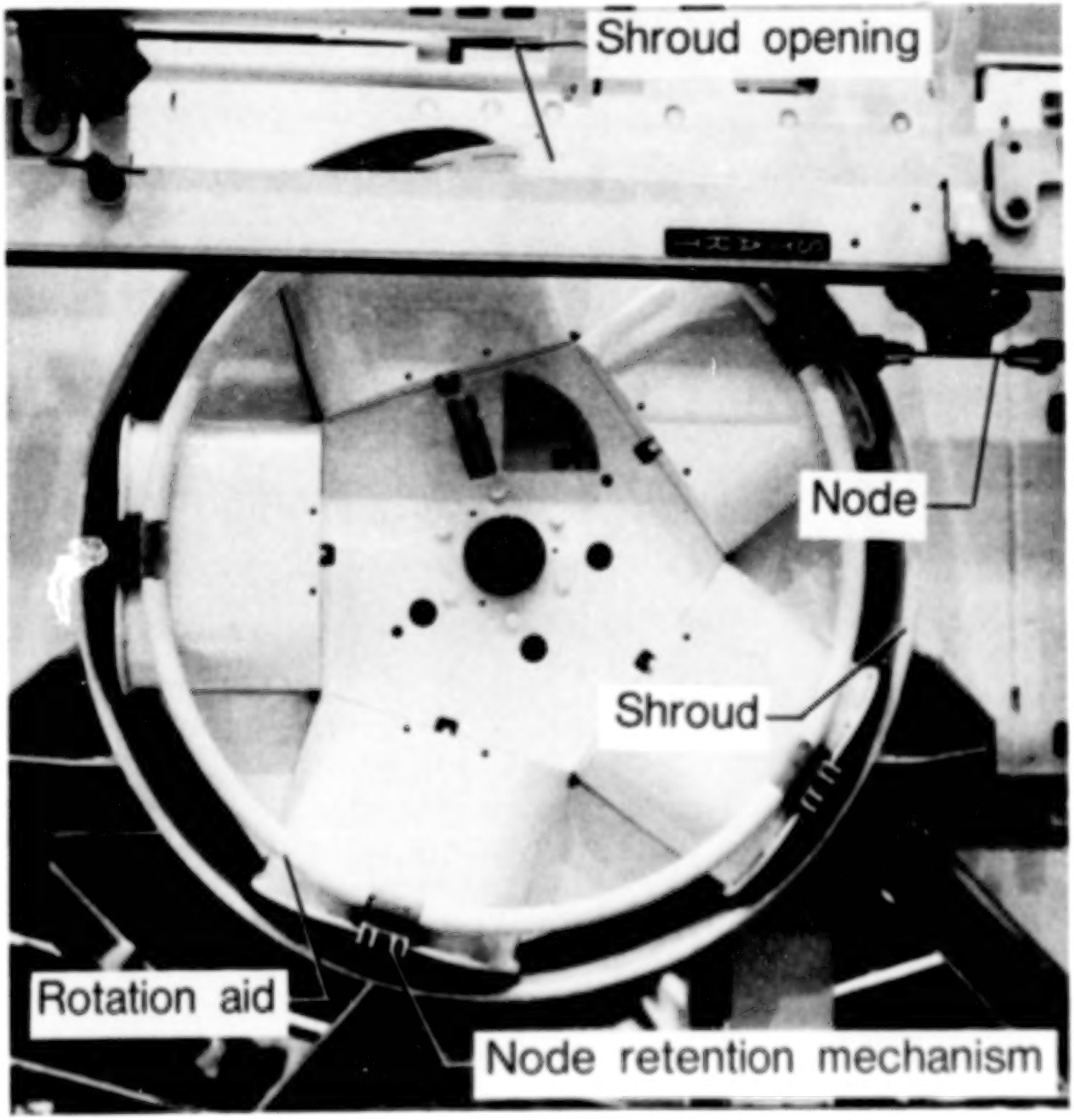
HARDWARE DESCRIPTION - NODE CANISTER

The node canister is circular in shape and rotates about a central shaft. It is locked into its launch/landing orientation by a spring loaded pin and backup quick release pin. It is composed of five separate compartments, each housing six nodes with the remaining three nodes stowed at the midpoint of each guide rail on the assembly fixture. This system is manually rotated inside a shroud with an opening large enough to remove the nodes from one compartment at a time. The nodes are retained in the individual compartments by node retention mechanisms which rotate inside the shroud and can be pivoted out of the way at the shroud opening for removal and stowage of the nodes.



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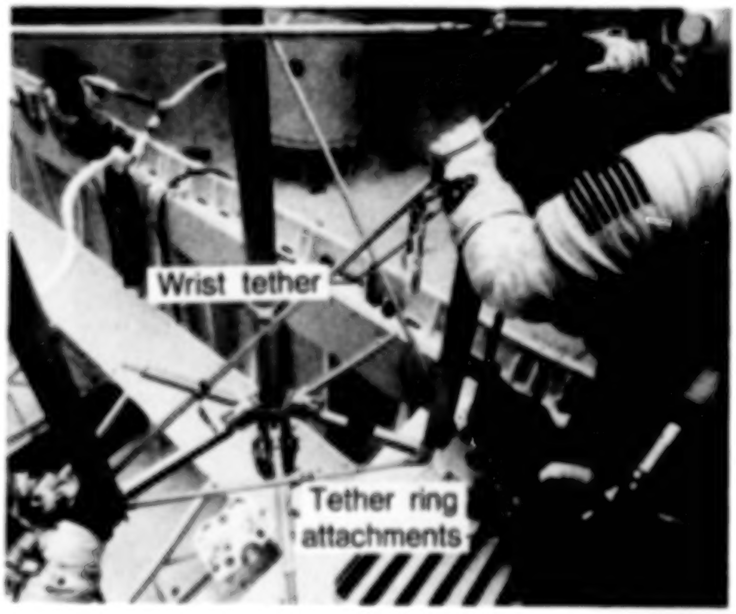
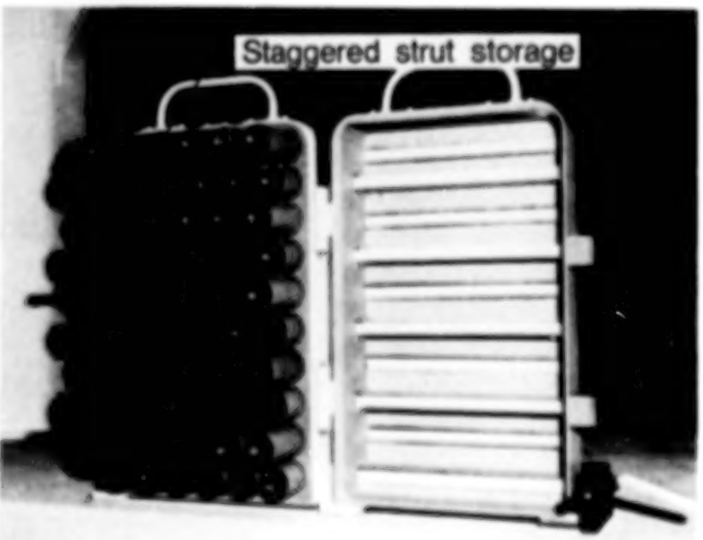
DEVELOPMENT PROBLEMS AND SOLUTIONS - TETHERING

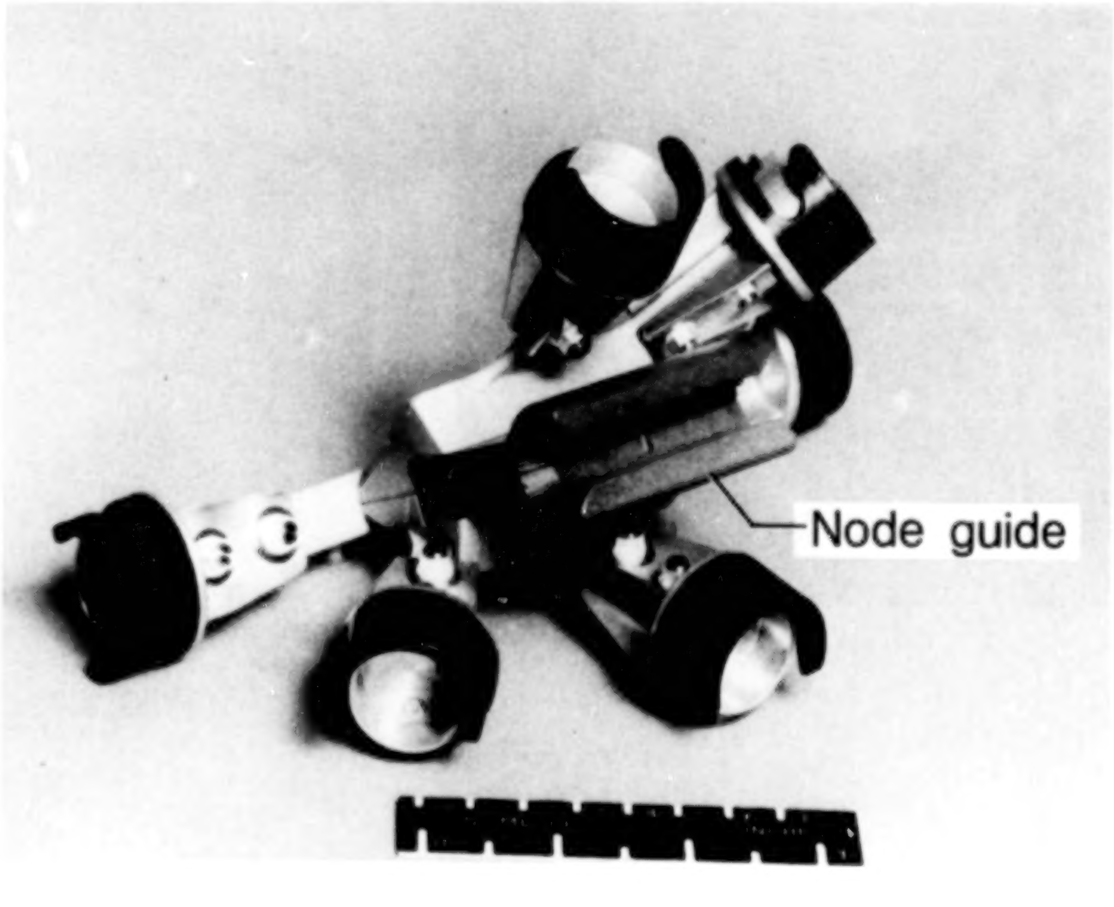
There was an original requirement to tether each node and strut prior to being removed from its stowage canister and remain tethered until the component had been securely integrated into the structure. Through testing, this proved to be a very cumbersome, time consuming, and hand intensive process; and with the support of the astronauts this requirement was waived. This allowed the tether ring attachments to be removed from the struts which required that another means be provided for removing the struts from the canisters. The resulting design provided for staggered stowage of struts in the canister which allowed for relatively easy removal and replacement of the struts. The node canister design had always required that the nodes be removed from the canister directly by the astronaut. Therefore the waiver of the tether requirement necessitated no design changes to the nodes or the node canister.





DEVELOPMENT PROBLEMS AND SOLUTIONS - COATINGS

With so many metallic surfaces rotating, sliding, and interfacing directly in close tolerance joints, proper coatings to minimize friction and increase the wear characteristics of these materials were of immediate concern. Although these problems surfaced in all the major components, the primary area of concern was with the truss structure sliding on the assembly fixture. The particular pieces of hardware involved in this operation were the truss structure node guides manufactured from 7075-T73 aluminum which slid on the 0.500-inch diameter stainless steel rods attached to the ends of the guide rails on the assembly fixture. A synergistic coating process was chosen for each of these items and proved to be reasonably effective in preventing galling and allowing the hardware to function as designed.



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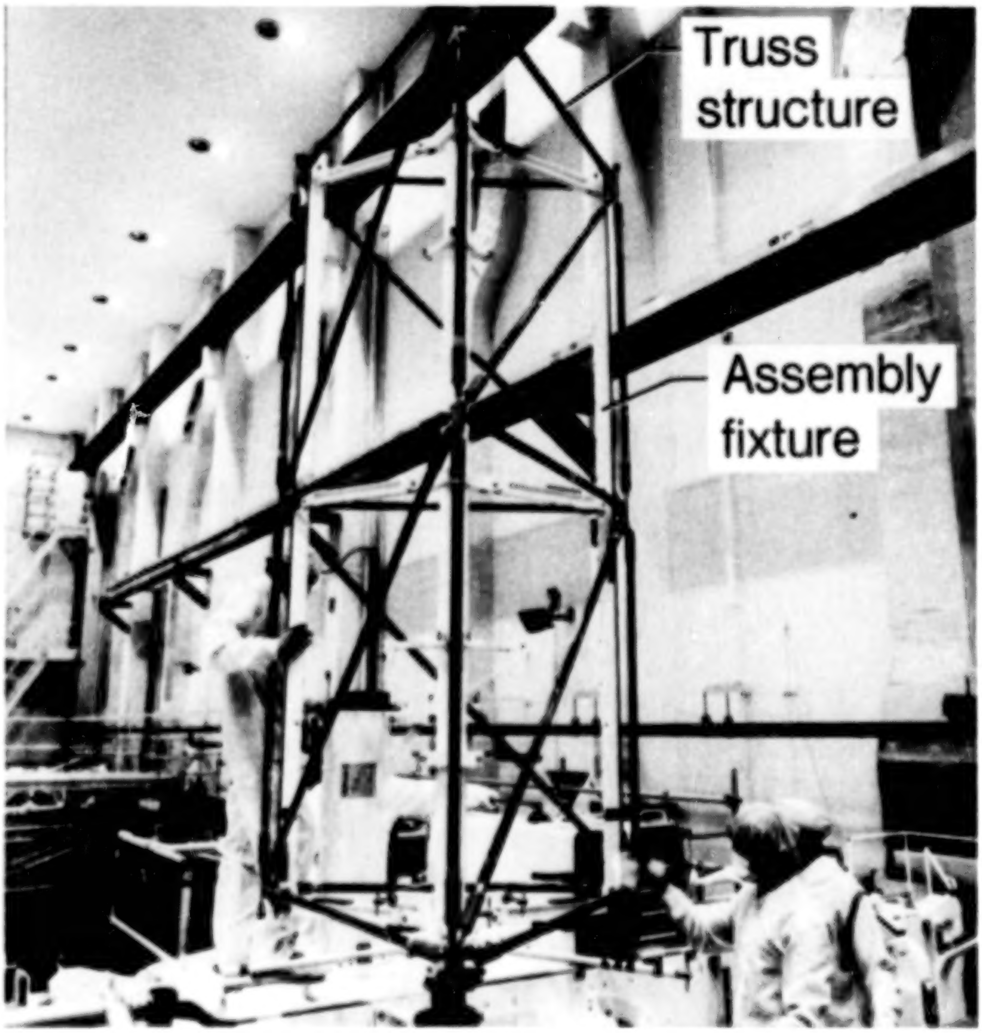
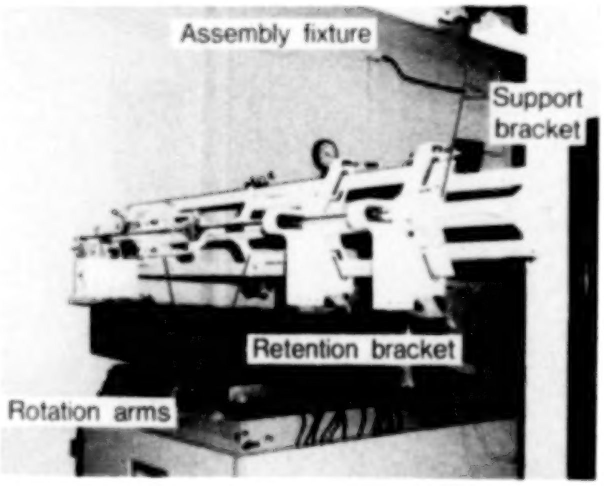
DEVELOPMENT PROBLEMS AND SOLUTIONS - TRUSS ASSEMBLY

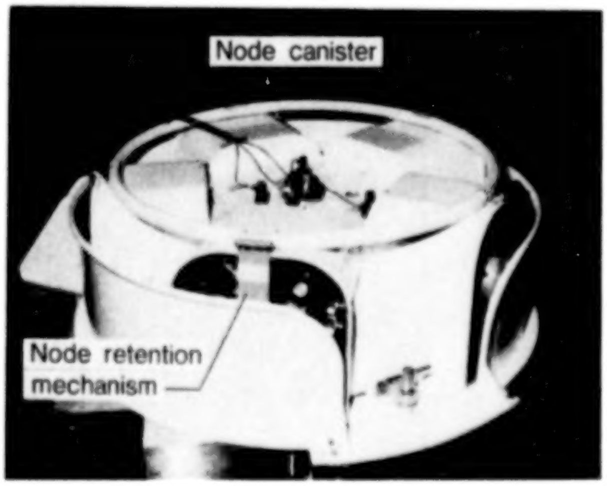
In order for the truss structure to exhibit reasonable structural characteristics, it was necessary to minimize the tolerance in the joint between the strut and node. For the ACCESS flight hardware, this tolerance was 0.001-inches which did not allow adequately for tolerance buildup in the manufacturing and assembly of the hardware or for the expected on-orbit thermal gradients. This concern was addressed by controlling the tolerance buildup of the individual parts and proper fixturing for the assemblies. The thermal gradients were minimized by selecting specific coatings and insulation material for the assembly fixture and truss structure. The entire system was then made more tolerant of the changes in the geometry of the structure by adding flexible bushings to the assembly fixture. This approach was verified by physically varying the lengths of the struts while mounted on the assembly fixture to determine the maximum allowable changes in lengths of the struts. These changes in length of the struts corresponded directly to thermal gradients between the truss structure and the assembly fixture which were predicted by a very detailed thermal model.



DEVELOPMENT PROBLEMS AND SOLUTIONS - VIBRATION TESTING

A number of problems were encountered during the vibration testing of the training hardware, in particular with the assembly fixture and the node canister. The assembly fixture required that two vertical rail retention brackets be added, the rotation arms and stowage brackets be modified, and that a radial arm support bracket be added in order for the assembly fixture to pass the vibration tests. Even with these extensive modifications the first mode frequency for the Z-axis was 32 hz which was 3 hz less than the design requirement and required specific attention during the coupled loads analyses. The node canister required that a node retention mechanism be added to each node stowage compartment in order to retain the nodes securely in place during vibration testing.





TESTING

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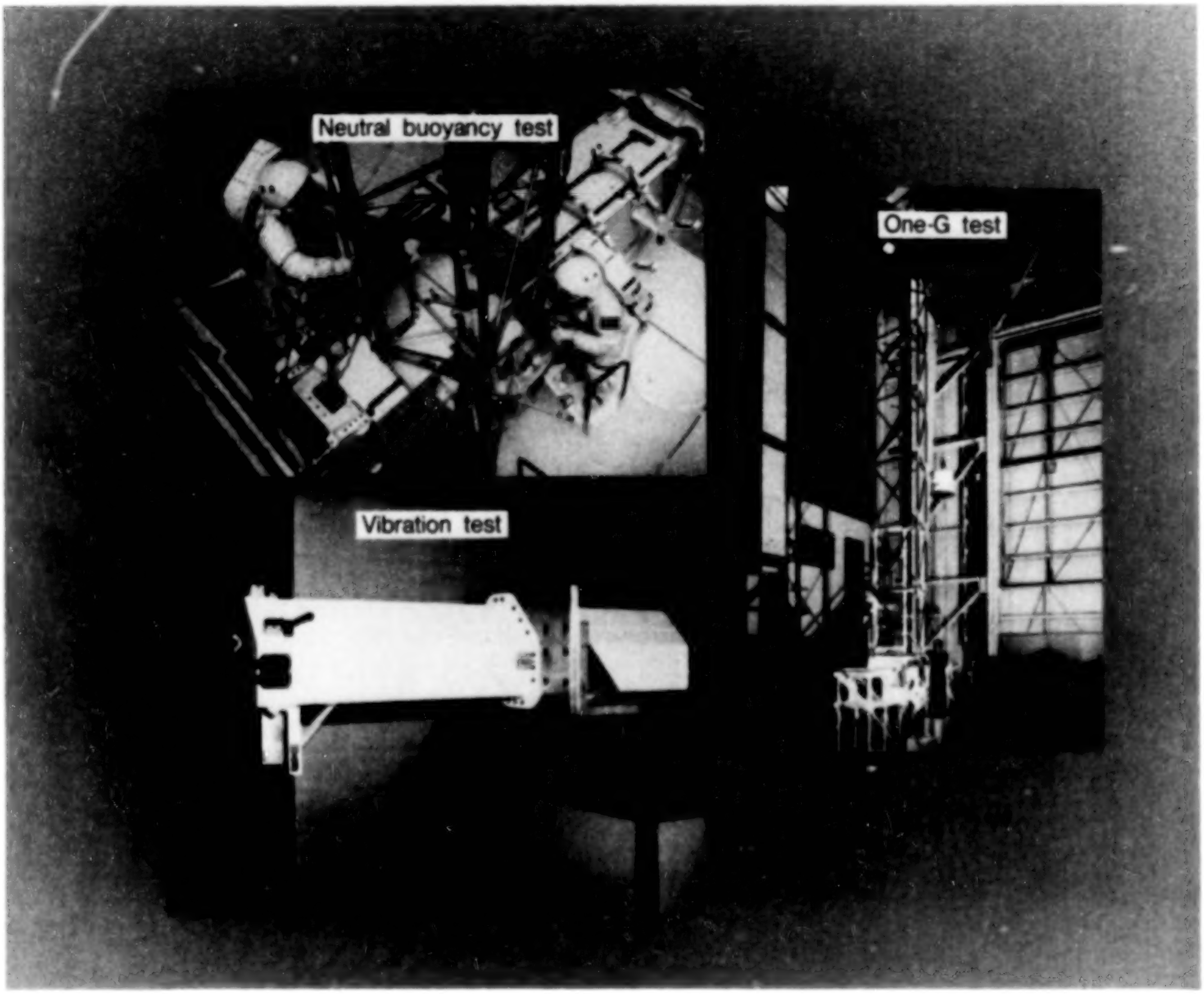
Various functional and environmental tests were conducted on both the ACCESS training and flight hardware. The training hardware was subjected to extensive simulated zero-G tests at the Marshall Space Flight Center's Neutral Buoyancy Simulator and the Weightless Environmental Test Facility (WETF) at the Johnson Space Center. These tests were used to verify that the hardware functioned as designed, to develop assembly procedures and timelines, and to train the astronauts prior to flight. One-G tests were conducted on the training and flight hardware to develop procedures and to verify that the hardware functioned properly. Both sets of hardware were subjected to a series of vibration tests which simulated the STS lift-off and landing environments. These tests were used to determine the first mode frequencies, amplification factors, and to insure survivability of the individual components. A series of thermal tests was conducted on the training hardware to insure proper functioning of the hardware and to verify specific inputs to the thermal model.



CONCLUSIONS

Several items were found to be of immense value in the design and development of the ACCESS hardware. The early availability of mock-up and engineering test hardware helped to develop the concept and prove the feasibility of the experiment. The extensive neutral buoyancy testing was invaluable in developing the procedures and timelines, proving that the hardware functioned as intended, and effectively training the astronauts. The early involvement of the crew systems/astronaut personnel was extremely beneficial in shaping the design to meet the EVA compatibility requirements. Also, the early definition of coupled loads and on-orbit dynamic responses can not be overemphasized due to the relative uncertainty in the magnitude of these loads and their impact on the design.

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N88-10874

MISSION PECULIAR EQUIPMENT SUPPORT STRUCTURE
A PLATFORM FOR SPACE CONSTRUCTION

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Space Construction Conference
Langley Research Center
Hampton, Virginia
August 6-7, 1986

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INTRODUCTION

America's Space Transportation System (STS), the Space Shuttle, requires carriers to support payloads in the cargo bay. As a result, the Mission Peculiar Equipment Support Structure (MPESS) was designed to carry partial payloads aboard the Shuttle. With completion and approval of the MPESS design, Teledyne Brown Engineering built six structures and delivered them to the National Aeronautics and Space Administration (NASA).

The MPESS is a lightweight carrier that bridges the Shuttle payload bay from sill to sill and occupies approximately one-fourth of the bay. The MPESS attaches to the sides and bottom of the Shuttle cargo bay, and there are 30 or more locations where it can be positioned. It can support 1,916 kilograms (4,225 pounds) of payload. Its basic construction consists of an upper section for experiment attachment and a lower truss type section that provides additional support, stability, and load carrying capability. The basic MPESS carrier can be outfitted with equipment to become a laboratory for scientific research or a platform for construction or deployment of large space structures.

Two space construction experiments, the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS) were mounted on the MPESS inside the Space Shuttle payload bay. For the EASE/ACCESS mission, the MPESS served as an equipment carrier and as a work platform for the two astronauts who assembled the structures in orbit. While the MPESS was somewhat benign compared to the experiment hardware, it worked ideally as a platform for constructing the two large space structures. The EASE/ACCESS mission was highly successful, and results from the mission are contributing significantly to ongoing space programs.

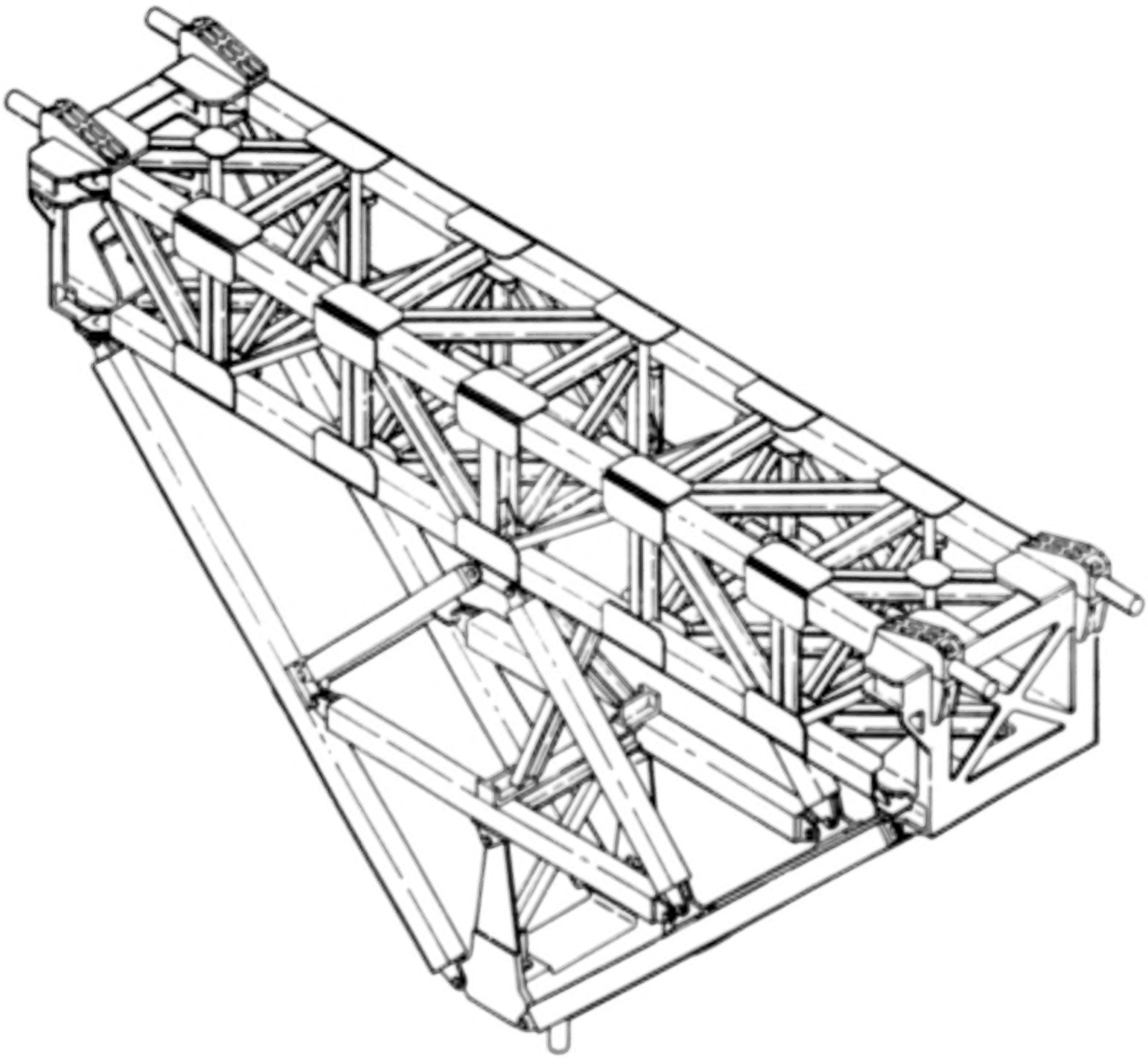
CUSTOMIZING THE MPESS FOR THE EASE/ACCESS PAYLOAD

NASA Headquarters selected the EASE and ACCESS experiments and assigned them as a payload to be flown aboard Space Shuttle mission 61-B from November 26 to December 2, 1985. The Marshall Space Flight Center (MSFC) Spacelab Payload Project Office was responsible for managing the EASE/ACCESS mission. This responsibility included selecting the appropriate payload carrier for the two experiments and designing a plan for integrating the experiments with the carrier to form the payload.

The MPESS was selected as the EASE/ACCESS carrier because it was available for flight in the inventory of NASA hardware. On previous missions, the MPESS was used to support scientific instruments and a large deployable space structure This successful track record suggested that the MPESS would be a stable work platform for the EASE/ACCESS construction experiments yet take a minimal amount of space in the payload bay.

Teledyne Brown, the MSFC Payload Mission Integration Contractor, designed and fabricated the MPESS for NASA and customized it for the EASE/ACCESS payload. The MPESS had to be outfitted with equipment for mounting the experiments, canisters for stowing equipment, and restraints for aiding crew members during the Extravehicular Activity (EVA).

In its basic form, the MPESS is 70 centimeters (27.5 inches) from front to back, 441 centimeters (173.5 inches) wide, and 262 centimeters (103 inches) deep with the top surface approximately level with the Shuttle cargo bay sill and the triangular base reaching to an attach point at the bottom (keel) of the cargo bay. Four standard trunnions join the MPESS with the side of the Shuttle. The main structural members are 10 centimeter by 10 centimeter (4 inch by 4 inch) aluminum alloy square tubes with interconnecting members dividing the upper platform into six sections or bays. The members and diagonal crossmembers are joined by stainless steel fasteners. Figure 1 shows the basic MPESS design.



BASIC MPESS

FIGURE 1

Structural members may be added to the basic MPESS to accommodate an assortment of experiment equipment. This type of construction enables the support structure to accommodate experiments of various sizes and shapes. Its open, truss-type construction also allows access for experiment installation and removal. Structures may be attached at standard bolt locations on the MPESS or may require the use of unique interface hardware or brackets to adapt the experiment to the support structure bolt locations.

The first step in tailoring the MPESS for the EASE/ACCESS payload was to design a blueprint showing the approximate locations of the experiment hardware on the equipment support structure. The plan called for EASE beams to be mounted on the front face of the triangle-shaped MPESS structure and for connector clusters (nodes) and one base cluster to be mounted on top of the platform. For ACCESS, the struts were to be stowed inside two canisters mounted on top of the MPESS; nodes were to be stowed inside a rotating, circular canister attached to the back side of the MPESS; and an assembly fixture on which ACCESS was built was to be clamped on the back side of the MPESS in a horizontal position parallel to the top of the MPESS platform. Figures 2 and 3 show the final MPESS configuration with the EASE/ACCESS equipment attached.

Before the equipment could be mounted in this configuration, Mission Peculiar Equipment (MPE) had to be designed to provide an interface for attaching the hardware to the MPESS. Initially, Teledyne Brown worked with MSFC to design nine interface plates, each approximately 86.3 centimeters by 96.5 centimeters (34 inches by 38 inches); three plates each were to be mounted to the front, top, and rear of the MPESS.

These initial plates were one inch thick; however, as weight of the experiment hardware increased, the total payload weight had to be reduced to stay within the payload's weight limits. Lighter plates were substituted in non-critical areas, but the plates remained an inch thick at load carrying points where hardware was to be directly attached. The final configuration used thin interface plates bridging areas between the heavier mounting plates. A total of 24 plates were used with ten plates on the top, nine on the back and, five on the front of the MPESS. Some of the attachment plates were further machined to lighten them after stress tests indicated that they could be lighter without affecting their load carrying capacity. To reduce weight even further, panels behind the EASE beams were covered with Beta cloth; heavier material was not needed because no equipment was mounted here, but covering was required to prevent the EASE beams from becoming wedged inside the MPESS framework. These techniques reduced the weight of the MPESS from 518 kilograms (1,140 pounds) to 195 kilograms (430 pounds) without compromising safety.

Since the MPESS was to serve as a work station for the astronauts who would assemble the structures, crew aids were necessary. Handrails were needed to help the astronauts translate about the work area, and foot restraints were needed to anchor the astronauts in place as they assembled the structures. The location of these aids was critical to the success of both experiments, especially the ACCESS experiment because the astronauts were required to be anchored in the foot restraints as they built the structure bay by bay in assembly line fashion. (The EASE experiment was built with the astronauts working in fixed foot restraints and unrestrained while tethered.)

MISSION PECULIAR EQUIPMENT SUPPORT STRUCTURE

Rear View

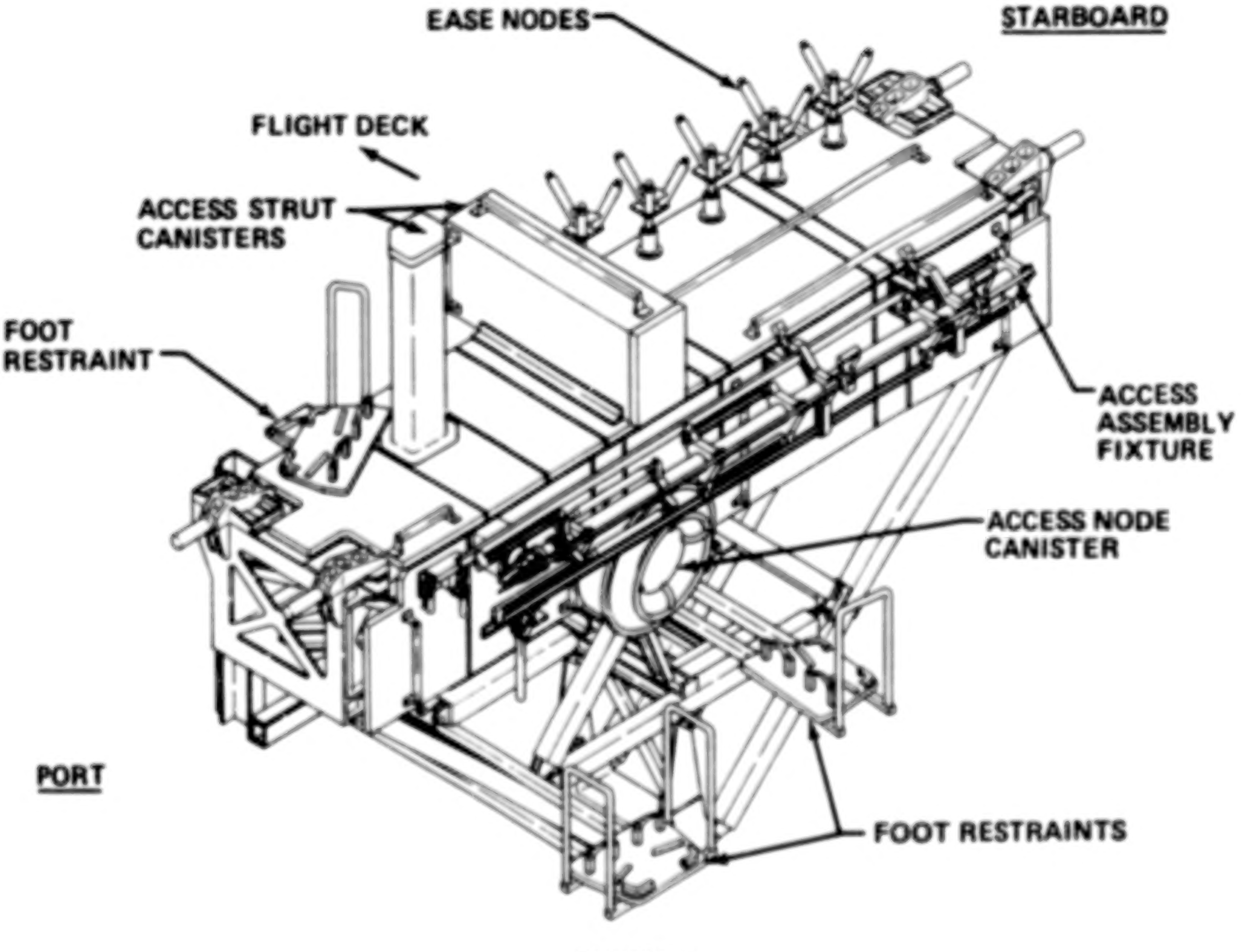


FIGURE 2

MISSION PECULIAR EQUIPMENT SUPPORT STRUCTURE

Forward View

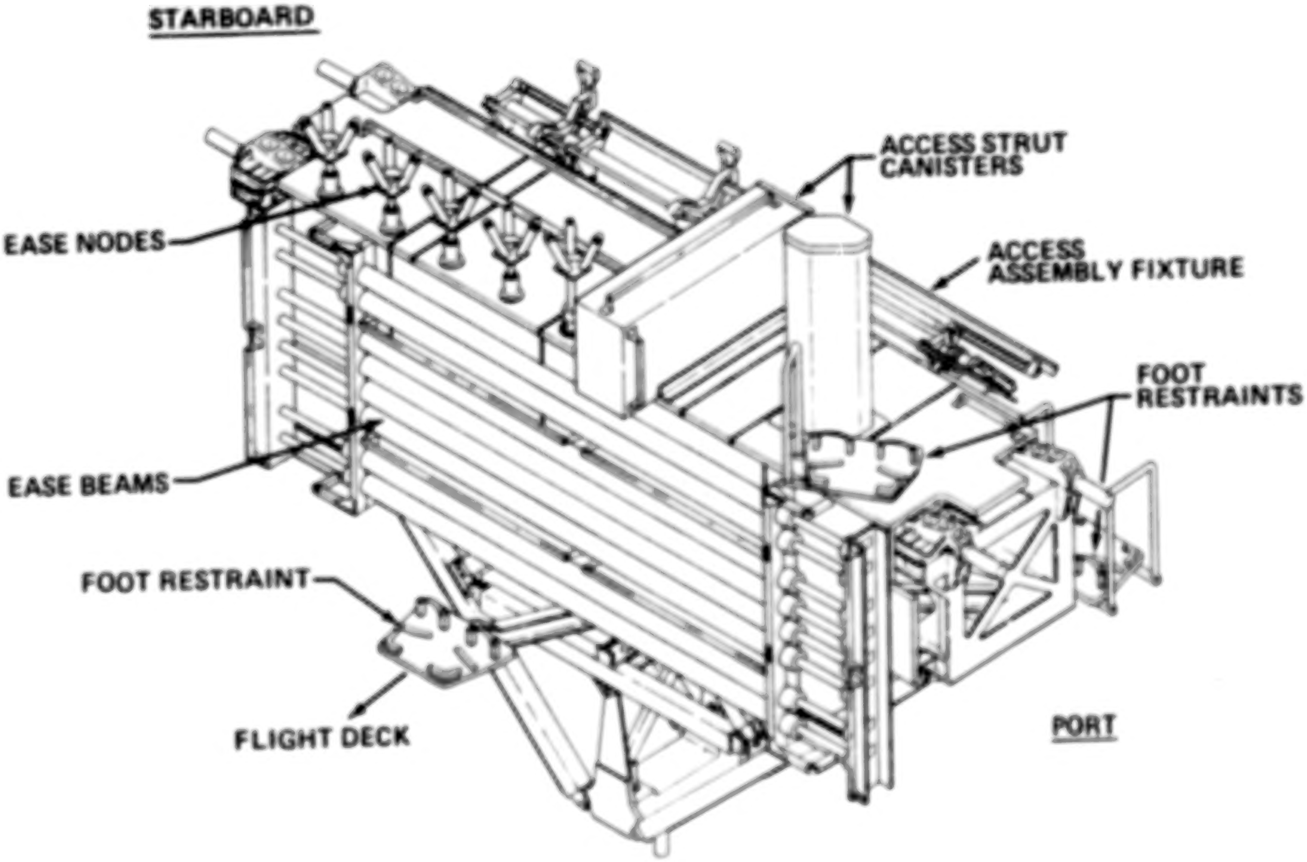


FIGURE 3

Experiment requirements dictated the general location for the handrails and foot restraints. (All crew aids were positioned per NASA standards MSFC-STD-412 and JSC-10615A) Since the crew members moved all around the MPESS at different times during the EVAs, handrails were positioned in several locations including the sides of the MPESS and on the ACCESS strut and node canisters. Foot restraints used for ACCESS were attached to the top and forward side of the MPESS. A foot restraint used for the EASE experiment was located on the forward side of the MPESS where the EASE beams were clamped.

Before specific astronauts were named to the mission, anthropometric standards were used to determine temporary locations for the handrails and foot restraints. It was critical that these crew aids be located for safety and ease of operations. This meant that the restraints had to be positioned so that each crew member could reach designated parts of the structures. For instance, the EVA astronaut had to be able to reach the assembly fixture to connect nodes and struts and build each side of the ten cells that formed the ACCESS truss tower. For the EASE experiment, the crew member unstowing the beams had to be able to hand the beams to his partner working approximately 4 meters (2 feet) away at the top of the structure.

Once the crew was assigned to the mission, the two astronauts who would assemble the structures were measured for reach, body length, and other human factors data. The locations, height, and length of the foot restraints were adjusted continually as a result of several neutral buoyancy simulations in which the crew practiced working in foot restraints while assembling and disassembling the structures and doing other experiment tasks. Figures 2 and 3 show the final configuration for the EASE/ACCESS handrails and foot restraints.

With the completion of the design for the Mission Peculiar Equipment, the interface plates, handrails, and support brackets for the foot restraints were fabricated at Teledyne Brown Engineering facilities. These components were designed and built per established quality control criteria to provide flight quality hardware meeting all safety requirements; therefore, safety verification was assured.

Prior to the completion of manufacturing, the interface plates were attached to the MPESS. The handrails and foot restraint support brackets were attached to the MPESS for a fit check but they were removed and shipped in separate containers to Kennedy Space Center (KSC). The EASE components also were attached to the MPESS to ensure adequate fits and proper envelope clearances. After these checks, the MPESS was packaged and shipped to KSC for integration of the experiment hardware. At the Kennedy Center, the payload was assembled in the Operations and Checkout Building. Personnel from NASA and Teledyne Brown were on call as technical advisors and were present at KSC when the crew exercised the integrated hardware; however, no modifications were made to the MPESS at this time.

Other inspections and checks were performed by KSC personnel during and after integration to ascertain that the design and assembly of all systems were compatible with the requirements of the orbiter into which it was placed. During the KSC closeout inspection, personnel discovered that a handrail slightly interfered with the RMS envelope. After consulting with the crew, a decision was made to remove the handrail rather than modify it to a shorter height or change its location. No problems occurred on orbit as a result of removing this handrail.

ENSURING EFFICIENT OPERATIONS

Once the MPESS has been customized to support a particular payload, the next step is to ensure that it will work efficiently and safely. During the design, manufacturing, and integration process, Teledyne Brown supported additional efforts to ensure that the total integrated payload would fit properly in the cargo bay. Analyses were performed based on drawings and information supplied by the experimenters to ascertain the correct layout and envelope of the total integrated payload. This guaranteed that no part of the experiment payload would extend beyond the clearances for crew translation or would interfere with the operation of parts of the Space Transportation System such as the payload bay doors or the Remote Manipulator System (RMS).

In another study, loads at the points where the experiment hardware attached to the interface plates were analyzed. This research proved that the plates were strong enough to support loads induced on the hardware as the structures were assembled and also during launch and landing. No thermal analysis of the MPESS hardware was needed because similar data were already available from previous flights.

Another integral part of the EASE/ACCESS payload development was verification of safe and compatible interfaces in the MSFC Neutral Buoyancy Simulator (NBS). A mockup of the MPESS was designed and fabricated for several series of tests completed in the two-year period before the mission. These tests were critical in determining the proper placement of the foot restraint supports required by the crew for experiment operation and crew handrails required for translation between work stations. Teledyne Brown supported MSFC in these tests to assure trouble free operation of the MPESS and to collect data to refine the payload for on-orbit operations. Figure 4 shows EASE being assembled in the MSFC/NBS.

As the mission launch date approached, training took place in the MSFC/NBS and the Johnson Space Center Weightless Environment Training Facility (WETF). These tests focused on training the crew to assemble and disassemble the experiments and perform other tasks such as removing the assembled structures from the MPESS for manipulations and then reattaching them to the support structure. Even at this stage, hardware and operating procedures continued to be refined. Training activity culminated in joint integrated simulations during which the crew practiced critical EVA operations in the WETF while other personnel rehearsed their roles in supporting the flight from the ground.

When integrated into the cargo bay of the orbiter, the payload remained dormant until exercised by the crew members during the two EVAs. During the structural assemblies, the MPESS integration team along with the MSFC mission management team and the experimenters were on hand at both the JSC Customer Support Room (CSR) and the MSFC Huntsville Operations Support Center (HOSC) to provide technical expertise. Only one minor problem occurred; during the second EVA the

EASE ASSEMBLY IN THE MSFC NEUTRAL BUOYANCY SIMULATOR

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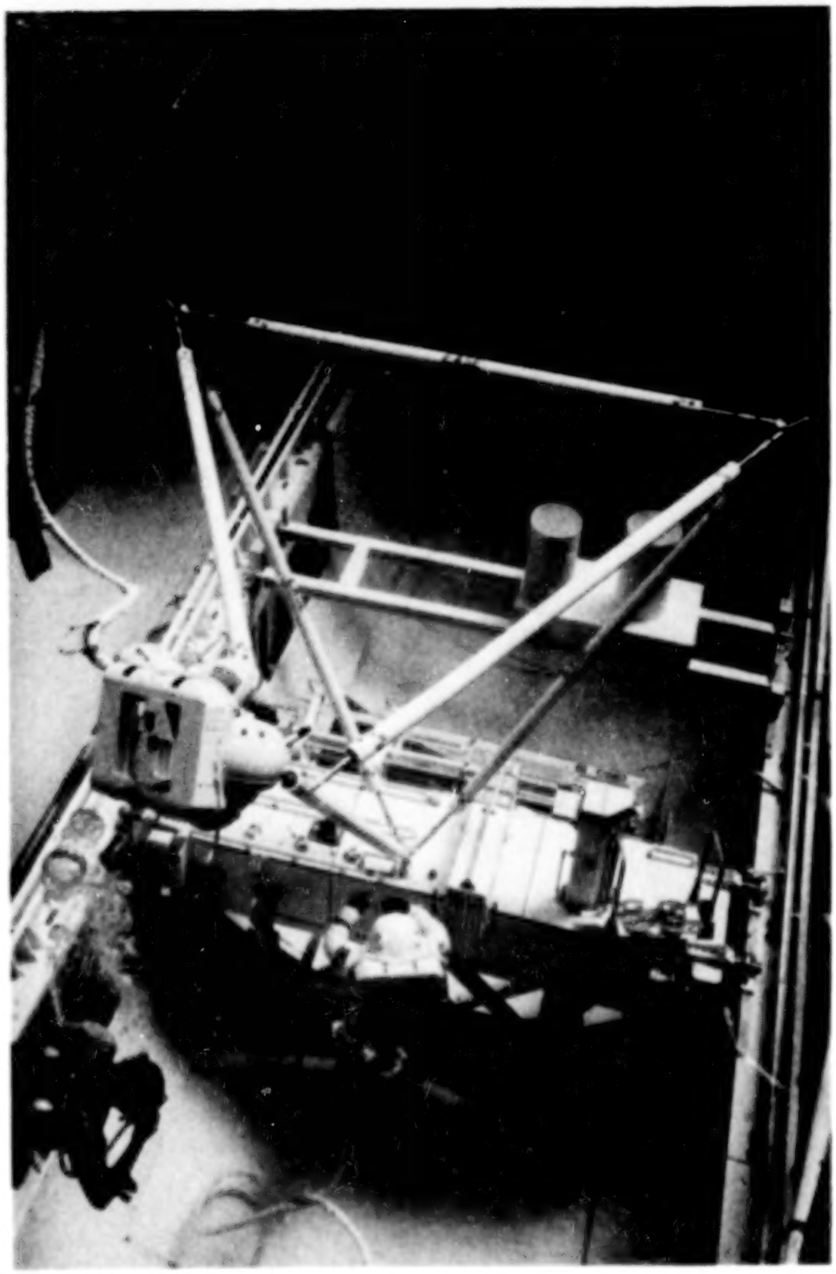
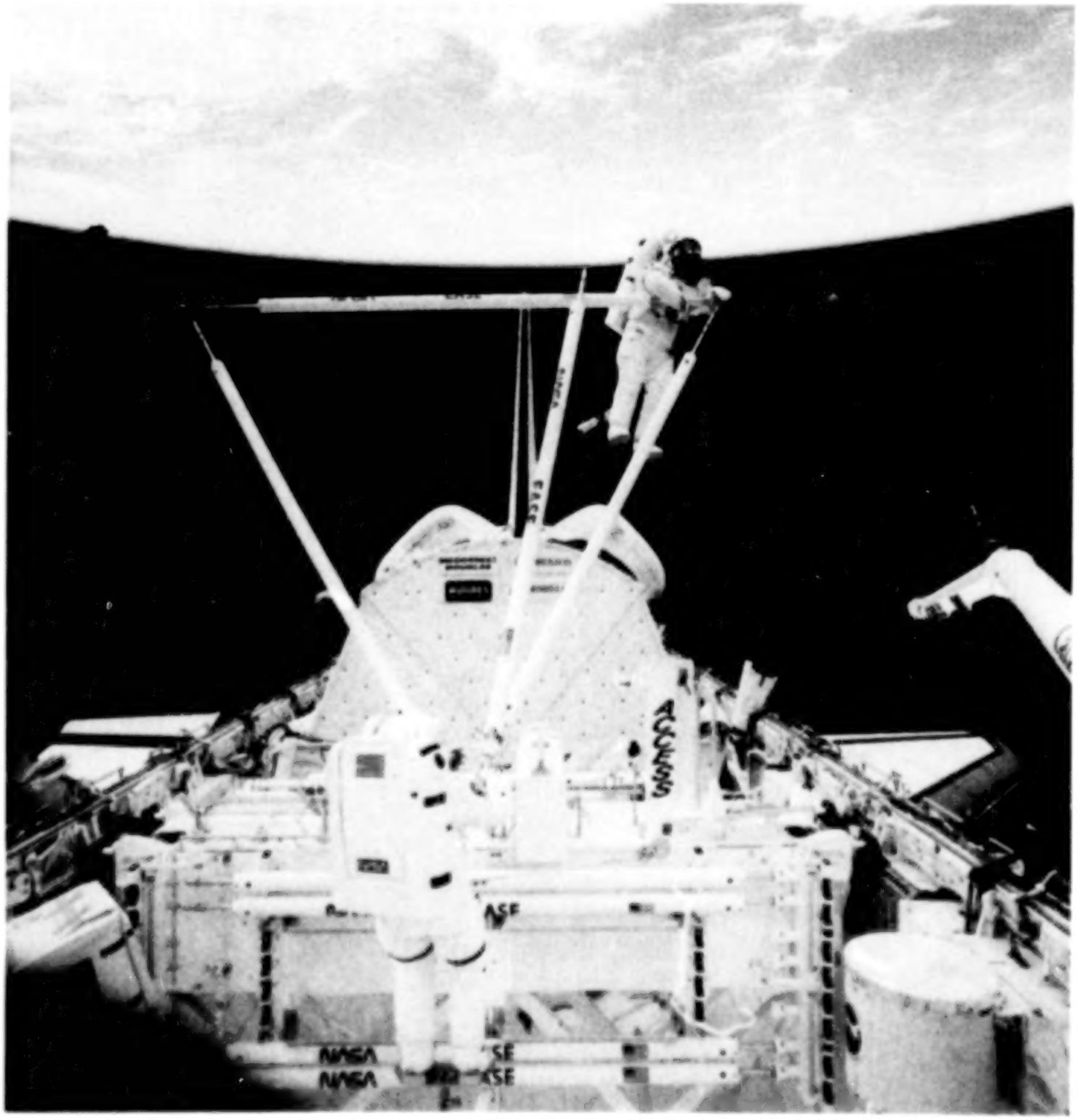


EASE base cluster connector could not be permanently reattached into the receptacle on the MPESS. The astronauts solved this problem by replacing the base cluster connector with a spare EASE node cluster and completing the experiment operations.

All other operations proceeded smoothly. During the first EVA, the astronauts assembled and disassembled the 12-meter (40-foot) ACCESS truss tower, and they assembled and disassembled the EASE tetrahedron several times. For the second EVA, they completed a variety of tasks including assembling and disassembling both structures from the Manipulator Foot Restraint (MFR) work station attached to the RMS and removing and manipulating the assembled structures. Throughout all these activities, the MPESS proved to be a stable platform. Figure 5 shows EASE being assembled in orbit.



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OTHER APPLICATIONS FOR THE MPESS

Several Mission Peculiar Equipment Support Structures have been used already for Shuttle missions. NASA currently has five of these carriers available for use in its inventory of STS equipment. Each MPESS has a 10-year shelf life and is designed to be flown for 10 missions; then it can be reused after it is requalified for flight.

Since the Shuttle must transport a variety of payloads, the support structure fills the need for a carrier system that can accommodate different experiments. However, unlike some other Shuttle carriers, the MPESS occupies only 0.91 meters (3 feet) of the cargo bay. Per NASA requirements the structure was designed to have a standard hole interface pattern, provide support at an elevated position, and have a natural frequency between the STS liftoff and landing frequency.

The first payload to use the support structure was the MSFC managed OSTA-2 payload composed of two sets of experiments for investigating materials processing in microgravity. This payload was launched on June 18, 1983 aboard STS-7 and was one of NASA´s first science missions on the Shuttle. One experiment, the Materials Experiment Assembly (MEA), sponsored by NASA studied two ways of mixing metals in microgravity to make advanced alloys and semiconductors. The other experiment sponsored by the West German Ministry for Research and Technology studied fluid dynamics and the way metals mix and disperse in low gravity.

Since the successful OSTA-2 mission, an MPESS has been used for Materials Science Laboratory (MSL) missions. For these payloads, the MPESS was outfitted with furnaces for studying alloys processing in space and acoustic levitators for fluid behavior research. Unlike the EASE/ACCESS payload, these missions required little crew interaction. Therefore, when the MPESS was customized for these missions, integration planners concentrated on providing the support structure with the thermal, electrical, and command and data handling systems necessary to support the experiments.

The first large structure flown aboard the MPESS was the OAST-1 payload dedicated to collecting data on large, deployable solar array panels similar to those being designed for future spacecraft. During this mission, a large 30.9-meter (100-foot) solar array was deployed successfully in several configurations from a canister mounted on top of the MPESS. When tailoring the MPESS for this experiment, investigators had to concentrate on connecting complex avionics equipment required to monitor and control the deployment and retraction of the array.

The MPESS has also been adapted for two Goddard Space Flight Center (GSFC) programs: Spartan and Get Away Special (GAS) canister bridges. For Spartan, the MPESS is equipped with an MSFC release/engage mechanism to which the Spartan carrier can be attached. The release mechanism allows Spartan to be deployed and reattached by the RMS. For the GAS bridge program, any combination of 5 to 12 canisters, weighing from 158.8 to 181.4 kilograms (350 to 400 pounds), can be mounted to the sides of the MPESS. Get Away Specials can carry a variety of payloads including small, deployable satellites.

Upon completion of the EASE/ACCESS mission, experiment and MPE hardware were removed from the MPESS and returned to the appropriate organization. The MPESS was placed in the NASA hardware inventory at KSC. Numerous flights contemplated for the near future will use the MPESS to support a variety of payloads currently under development, including additional Materials Science Laboratory missions and on-orbit phased array radar simulation experiments. The evolution of the MPESS carrier fleet has resulted in a system which provides low cost, quick turnaround, and frequent flight opportunities for users.

N88-10875

MARSHALL SPACE FLIGHT CENTER'S ROLE IN EASE/ACCESS MISSION MANAGEMENT

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August 6-7, 1986

ABSTRACT

The Marshall Space Flight Center (MSFC) Spacelab Payload Project Office has been responsible for the mission management and development of several successful payloads. Two recent space construction experiments, the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS), were combined into a payload managed by the center. EASE/ACCESS was flown aboard the Space Shuttle during a week-long mission from November 26 to December 2, 1985. The EASE/ACCESS experiments were the first structures assembled in space, and the method used to manage this successful effort will be useful for future space construction missions.

For the EASE/ACCESS mission as well as others, the MSFC mission management team ensures that the payload satisfies the needs of the investigators, is compatible with Shuttle resources, and operates safely during flight. The mission management team coordinates all activities that must be completed before launch, during payload operations, and after landing. During the mission, they are responsible for resolving any payload problems and aiding the crew and investigators in collecting data. The mission management team works closely with other NASA centers, especially the Johnson Space Center and the Kennedy Space Center.

This paper addresses the MSFC mission management responsibilities for the EASE/ACCESS mission and discusses how lessons learned from this mission can be applied to future space construction projects.

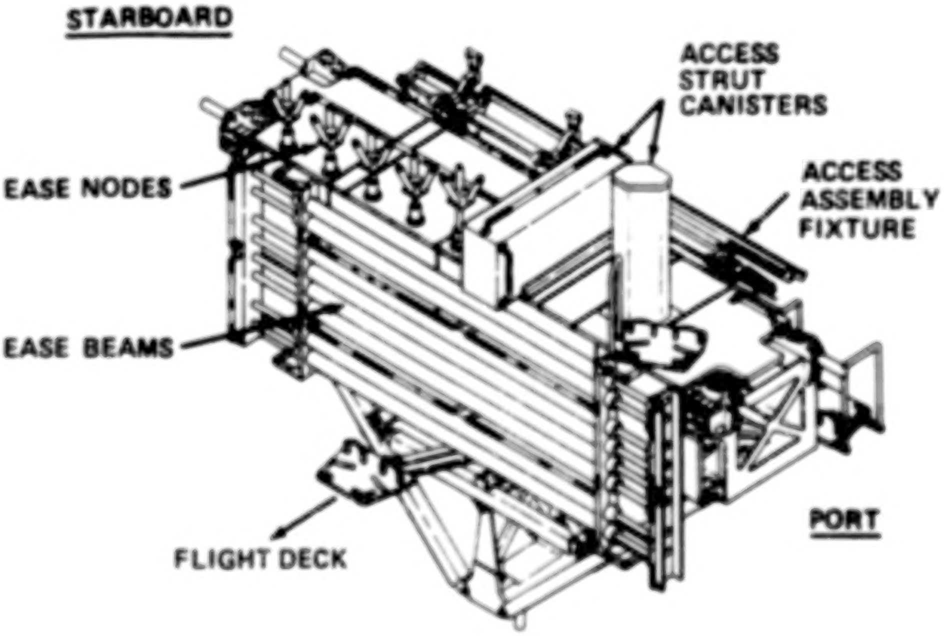
BACKGROUND

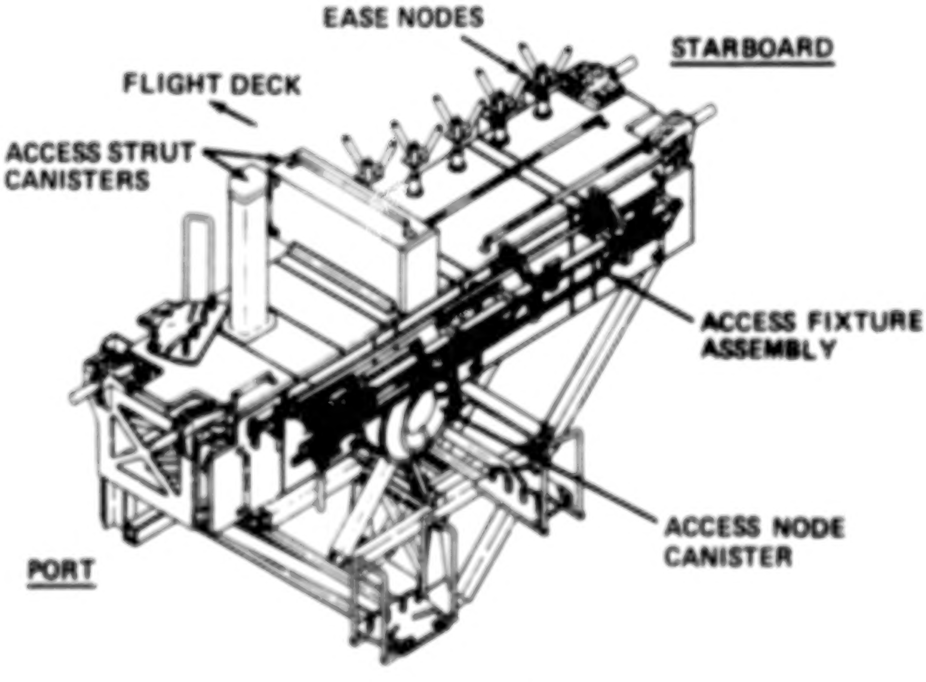
The payload mission manager at Marshall Space Flight Center (MSFC) must ensure experiments are integrated into a payload that can be flown successfully aboard the Space Transportation System (STS). This process begins when the National Aeronautics and Space Administration (NASA) Headquarters authorizes MSFC to integrate a set of experiments and requests that a payload be manifested on a Space Shuttle flight.

The MSFC Spacelab Payload Project Office (SPPO) has been responsible for managing several successful missions, including three Spacelab missions in which scientific laboratories occupied the entire Shuttle payload bay and partial payloads such as the early Shuttle science missions, OSTA-2 and OAST-1, and the Materials Science Laboratory missions. MSFC has developed a mission management technique to ensure that payloads satisfy the needs of the experimenters, utilize Shuttle resources efficiently, and operate safely during flight. The management team coordinates all activities that must be completed before launch, beginning with preliminary design and continuing through payload integration and checkout. During the mission, they continue to aid the crew and investigators in collecting data and resolving problems.

Recently, the MSFC Spacelab Payload Project Office managed and integrated a payload of two space construction experiments: the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS). EASE and ACCESS were successfully assembled and disassembled during two extravehicular activities (EVAs) on November 29 and December 1, 1985. Since EASE/ACCESS was the first planned space construction mission, the experiments were kept simple, with the main goal being to study human performance during on-orbit construction. The techniques and approaches used in managing these experiments will be useful as more complex missions are planned during the Space Station era.

EASE/ACCESS was a partial payload; it filled one-fourth of the Shuttle cargo bay. The remainder of the bay was occupied by three deployable satellites. Figure 1 shows two views of the EASE/ACCESS experiment hardware mounted on the Mission Peculiar Equipment Support Structure (MPESS), a carrier which fits inside the Space Shuttle cargo bay.

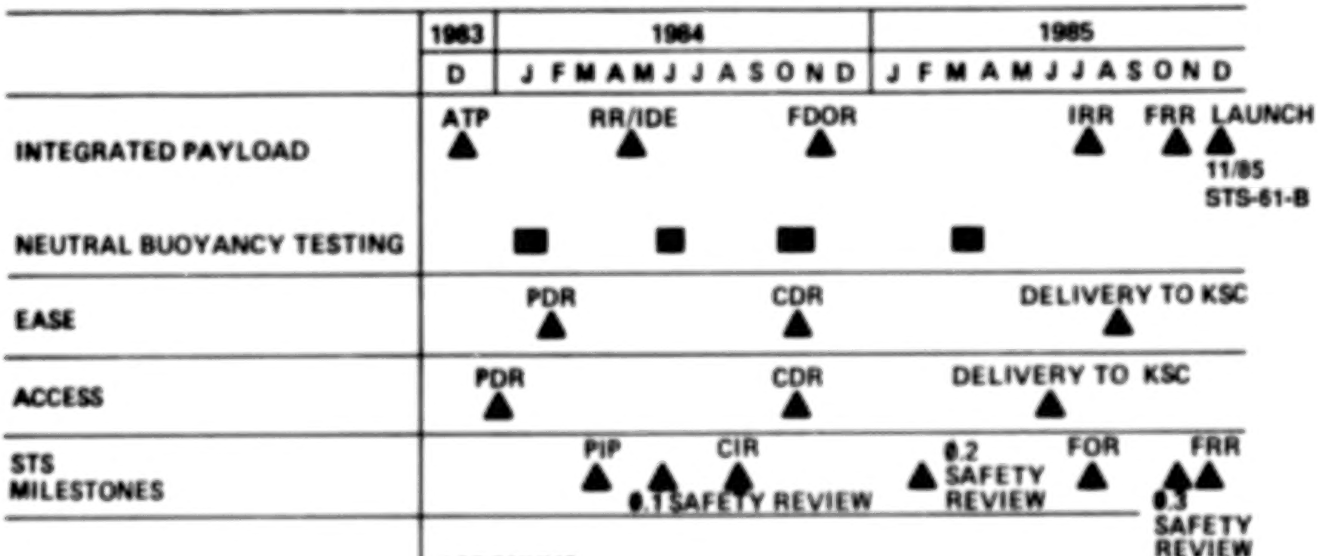




For the EASE/ACCESS mission, MSFC used an analytical integration process developed to manage partial payloads from payload definition through postflight activities. The steps of the process are similar for all partial payloads with emphasis on the payload's unique features. For example, EASE/ACCESS planning emphasized crew training and structural analysis, with minimal efforts for data processing. Other payloads such as the Materials Science Laboratory require little crew interaction, and therefore, planning efforts focus on other aspects of the mission.

As is shown in Figure 2, the integration activity began in December 1983 and ended with experiment operations aboard STS 61-B. As the integration schedule in Figure 2 shows, the completion of each phase of the program was marked with a design review. These reviews served to assure compatible development of all aspects of the integrated payload.

EASE/ACCESS INTEGRATION SCHEDULE



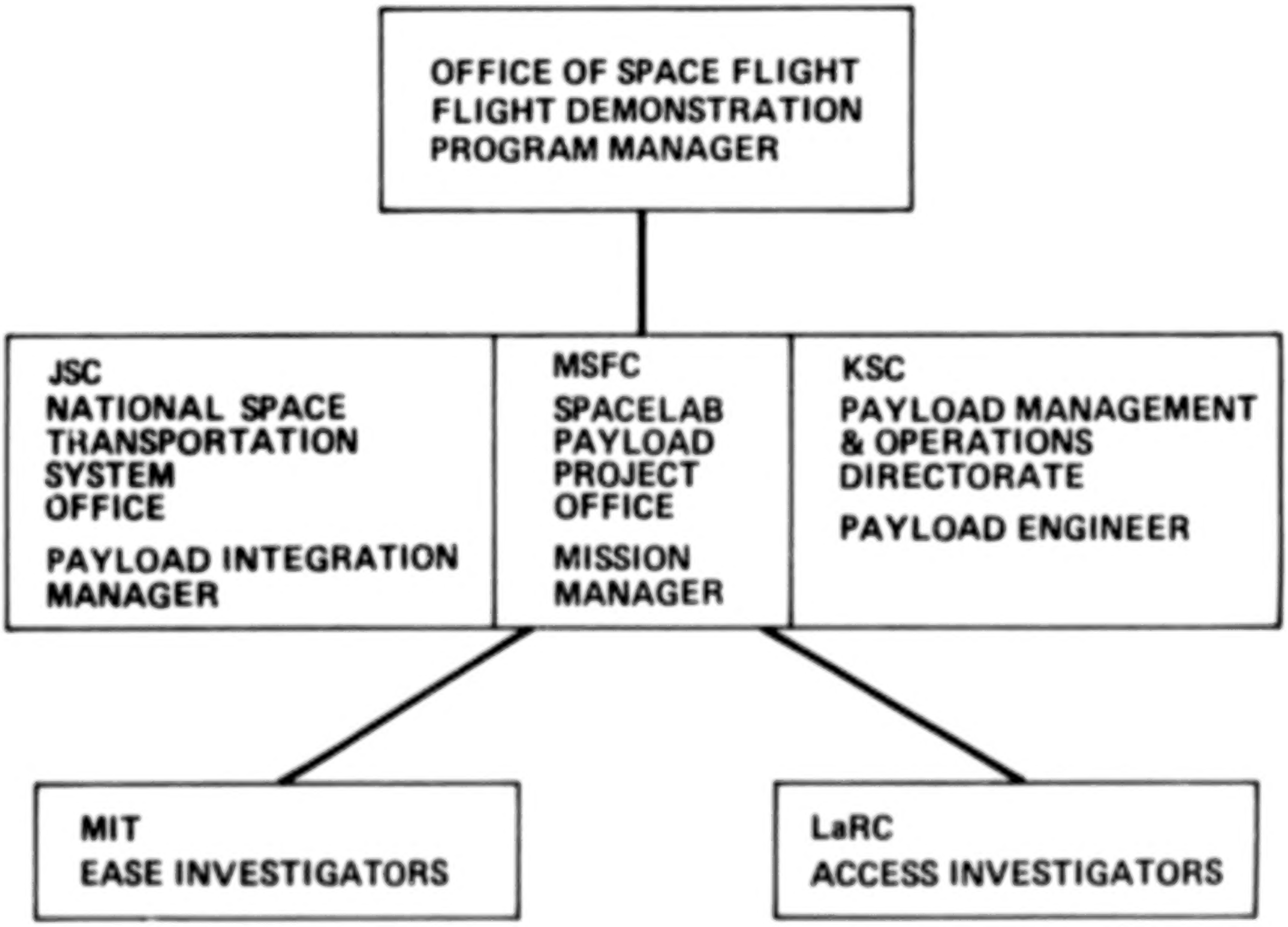
ACRONYMS

ATP	AUTHORITY TO PROCEED
RR	REQUIREMENTS REVIEW
IDE	INTERMEDIATE DESIGN EVALUATION
FDOR	FINAL DESIGN & OPERATIONS REVIEW
IRR	INTEGRATION READINESS REVIEW
FRR	FLIGHT READINESS REVIEW
PDR	PRELIMINARY DESIGN REVIEW
CDR	CRITICAL DESIGN REVIEW
PIP	PAYLOAD INTEGRATION PLAN
CIR	CARGO INTEGRATION REVIEW
FOR	FLIGHT OPERATIONS REVIEW

NASA CENTER RESPONSIBILITIES

Three NASA centers were primarily responsible for integrating the EASE/ACCESS payload: Marshall Space Flight Center, Johnson Space Center (JSC), and Kennedy Space Center (KSC). All three centers worked closely together throughout the development and flight of the payload. Figure 3 shows the organizational relationships between the three mission integration centers, NASA headquarters, and the experiment developers.

MISSION INTEGRATION MANAGEMENT RELATIONSHIPS


OFFICE OF SPACE FLIGHT
FLIGHT DEMONSTRATION
PROGRAM MANAGER
JSC
NATIONAL SPACE TRANSPORTATION SYSTEM OFFICE
PAYLOAD INTEGRATION MANAGER
MSFC
SPACELAB PAYLOAD PROJECT OFFICE
MISSION MANAGER
KSC
PAYLOAD MANAGEMENT & OPERATIONS DIRECTORATE
PAYLOAD ENGINEER
MIT
EASE INVESTIGATORS
LaRC
ACCESS INVESTIGATORS

The MSFC mission management team was responsible for analytically planning the EASE/ACCESS mission and providing Mission Peculiar Equipment (MPE), additional equipment needed to support the payload. The analytical integration process was directed by a payload mission manager who was ultimately responsible for integrated payload definition and design, verification of STS compatibility and safety compliance, and coordination of requirements with managers of supporting organizations. To fulfill these obligations, the mission manager relied on a team of integration engineers. The mission management team served as the liaison with the investigators. The EASE experiment was developed by the Massachusetts Institute of Technology (MIT) under contract to MSFC. The ACCESS experiment was developed by the NASA Langley Research Center.

The Johnson Space Center was responsible for gathering data on all the payloads assigned to the mission, defining the cargo, designing an integration plan for the entire cargo, certifying that the Shuttle and all payloads on board were safe, and planning on-orbit operations. MSFC provided the EASE/ACCESS payload requirements, and the JSC integration team used them to integrate EASE/ACCESS with the Shuttle and the rest of the payloads assigned to the mission.

The Kennedy Space Center was responsible for physically integrating the experiments into a payload, installing them in the Space Shuttle, and providing launch and landing support. The MSFC mission management team provided KSC with the specifications for checkout and integration of the experiments and Mission Peculiar Equipment.

PAYLOAD DEFINITION

Following the assignment of mission management responsibility to MSFC, several meetings are held with the experiment developers. At this point, usually the concept for each experiment is well defined, but experiment requirements have not been specified and hardware has not been designed. The mission management team and the investigators determine the requirements for each experiment and decide how the Space Transportation System and available support hardware can meet these needs.

ACCESS, a 12-meter (40-foot) high tower constructed with 93 struts and 33 nodes, and EASE, a tetrahedron-shaped structure made of 6 large beams and 4 connector clusters, had many of the same requirements. Both the EASE and ACCESS experiments called for the structures to be positioned forward in the payload bay for clear line of sight photography from the aft flight deck; for adequate clearance for suited EVA astronauts in the payload bay; and for a carrier for experiment hardware. With these demands in mind, MSFC engineers selected the Mission Peculiar Equipment Support Structure (MPESS) to serve as the carrier for the EASE/ACCESS payload. (Figure 1 shows the MPESS launch configuration.) The MPESS was selected because it was available, takes up a minimum of cargo bay space, provides adequate clearance for EVA astronauts, and requires a minimum of Mission Peculiar Equipment. Other available carriers were rejected because they failed to satisfy the requirements of the mission as efficiently. For instance, a Spacelab pallet was ruled out because it was heavier, took up more space than the MPESS, and required more Mission Peculiar Equipment. The MPESS bridged the Shuttle payload bay, serving as a work platform for the astronauts as well as an equipment carrier.

During the early stages of payload development, other standard STS equipment is identified for use by the experimenters. Using this equipment reduces experiment costs and enhances reliability. EASE/ACCESS made use of 16- and 70-mm film cameras, video cameras and recorders, foot restraints, and tethers from the STS inventory. However, an EASE experiment requirement to record time on two synchronized 16-mm film cameras required the modification of the standard cameras. With this modification, the two 16-mm cameras recorded stereoscopic images of the EVA astronauts at work.

As the experiment requirements are defined, the mission manager works with the experiment developers and JSC to determine if and how requirements can be met. Both EASE and ACCESS required locations in front of the other payloads. The experiments had to be forward enough in the payload bay to allow accurate photography from the aft flight deck but back far enough to leave room for the EVA astronauts to assemble the structures.

During payload definition, the MSFC team also provides experiment developers with design criteria for using the Space Shuttle. This includes environmental and safety design criteria as well as lists of available services and equipment such as the Remote Manipulator System (RMS). With this knowledge, the investigators define requirements placed on the Space Transportation System in a formal document, the Experiment Requirements Document (ERD), which is submitted to the MSFC mission manager. The ERD describes the experiment's requirements in the following areas: experiment operation and configuration, electrical, thermal, and command and data handling controls, physical integration plans, and ground operations support plans. The ERD is updated as the experiment evolves.

The MSFC mission manager uses the ERD and other information from the investigators to formalize payload requirements with JSC in the Payload Integration Plan (PIP), the master plan used to allocate STS resources for a specific payload. MSFC personnel helped prepare annexes to the PIP that identified details pertinent to EASE and ACCESS. Since the structures were constructed during EVAs, the assembly and disassembly process had to be identified in step by step procedures. Other annexes addressed various aspects of the mission: flight operations support by personnel working on the ground; crew training; command and data handling; equipment placement and stowage; launch site support; payload safety verification; and EVA activities and equipment.

After the basic payload is defined, the experiment developers begin preliminary design. For EASE and ACCESS, a great deal of conceptual work had already been accomplished before the experiments were assigned to a Shuttle flight. Investigators from Langley and MIT had already done research and neutral buoyancy testing with various large space structures. This experience helped them determine the appropriate structure size, configuration, and assembly procedure. ACCESS used an assembly line technique with the crew remaining at designated work stations and moving the tower along an assembly fixture as they assembled it bay by bay. EASE used an assembly technique with crew members working both in restraints and unrestrained. Neutral buoyancy mockups of the two structures were fabricated, and investigators refined the hardware design and assembly techniques.

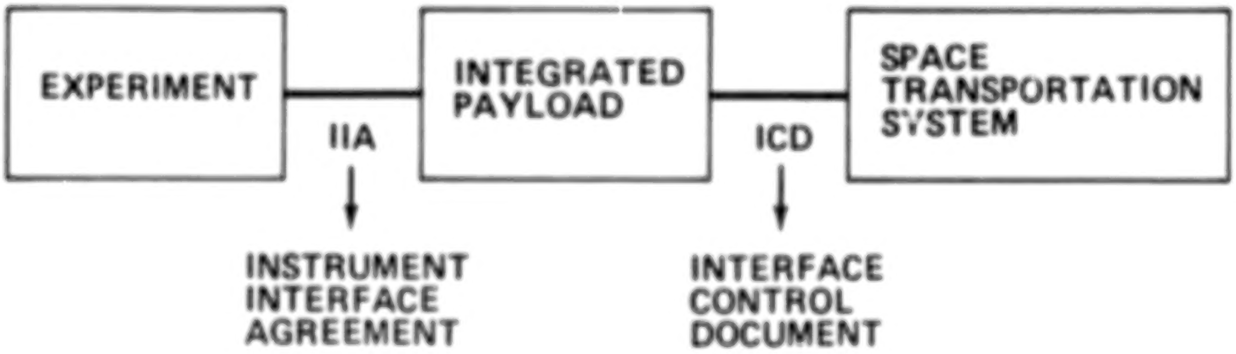
Throughout the hardware design and integration process, a series of formal design reviews play an important role in coordinating efforts. Figure 2 shows a schedule for reviews of the EASE/ACCESS payload. Each review occurs at a natural transition point in payload development. For example, the purpose of the Integrated Payload Preliminary Design Review is to finalize mission requirements, the baseline payload interfaces, the safety verification methods and begin planning for physical integration and flight support. The last review before delivery of hardware to KSC is the Integrated Payload Integration Readiness Review in which the payload is reviewed against the established requirements to verify payload safety and compatibility with the orbiter and other payload elements.

INTERFACE DEFINITION

Interfaces are defined between each experiment and the integrated payload and between the integrated payload and the STS. As shown in Figure 4, the experiment to payload interfaces are defined in the Instrument Interface Agreement (IIA), and the payload to STS interfaces are defined in the unique Interface Control Document (ICD). As all the payloads assigned to the mission and the individual experiments evolve, it is often necessary to reconsider the interface definitions. Changes are defined in the IIA which is used to obtain the agreement of the effected design groups.

Interfaces have to be defined for each subsystem of a payload including all the electrical, mechanical, and thermal connections between the experiment hardware and the carrier. An envelope drawing indicating maximum experiment size, limits of motion, and connector locations and mounting is documented. As the first space construction payload, EASE/ACCESS had simple interfaces, consisting mainly of structural and mechanical interfaces where the experiments, the MPESS, and support hardware were connected or attached; there were no requirements for electrical or power systems or microprocessor commands and data.

INTERFACE DEFINITION


EXPERIMENT
INTEGRATED PAYLOAD
SPACE TRANSPORTATION SYSTEM
IIA
ICD
INSTRUMENT INTERFACE AGREEMENT
INTERFACE CONTROL DOCUMENT

The principal interfaces vary with each payload. For EASE/ACCESS, crew interaction with the structures was a primary concern. It was critical that the experiments be compatible with the crew. The astronauts participated in experiment development tests and helped define details such as the location and number of foot restraints and handholds and the location and assembly instructions provided on decals placed on the flight hardware. The hardware materials met crew touch temperature limit standards. The hardware had to be easy to handle by a suited astronaut; this requirement resulted in the development of a harpoon, a pip pin with a tether, designed by the MIT experiment developers to restrain the large EASE beams during handling. It also resulted in the waiver of some requirements. The flight rule that all hardware handled during an EVA must be tethered was waived because tests verified that the small ACCESS struts could be manipulated safely and easily without tethers.

Interface definition continues to change and evolve until flight. Design solutions for changes are identified in formal documents and all effected groups are notified of changes. For instance, if it is determined that an extra handhold is needed on experiment hardware, investigators are informed of the requirement and given instructions to modify hardware to accommodate the change. In some cases, the investigators will request a modification. For instance, the Langley experiment developers added insulation to the ACCESS structural members to prevent thermal gradients from causing the hardware to bind.

SAFETY AND VERIFICATION PROCESS

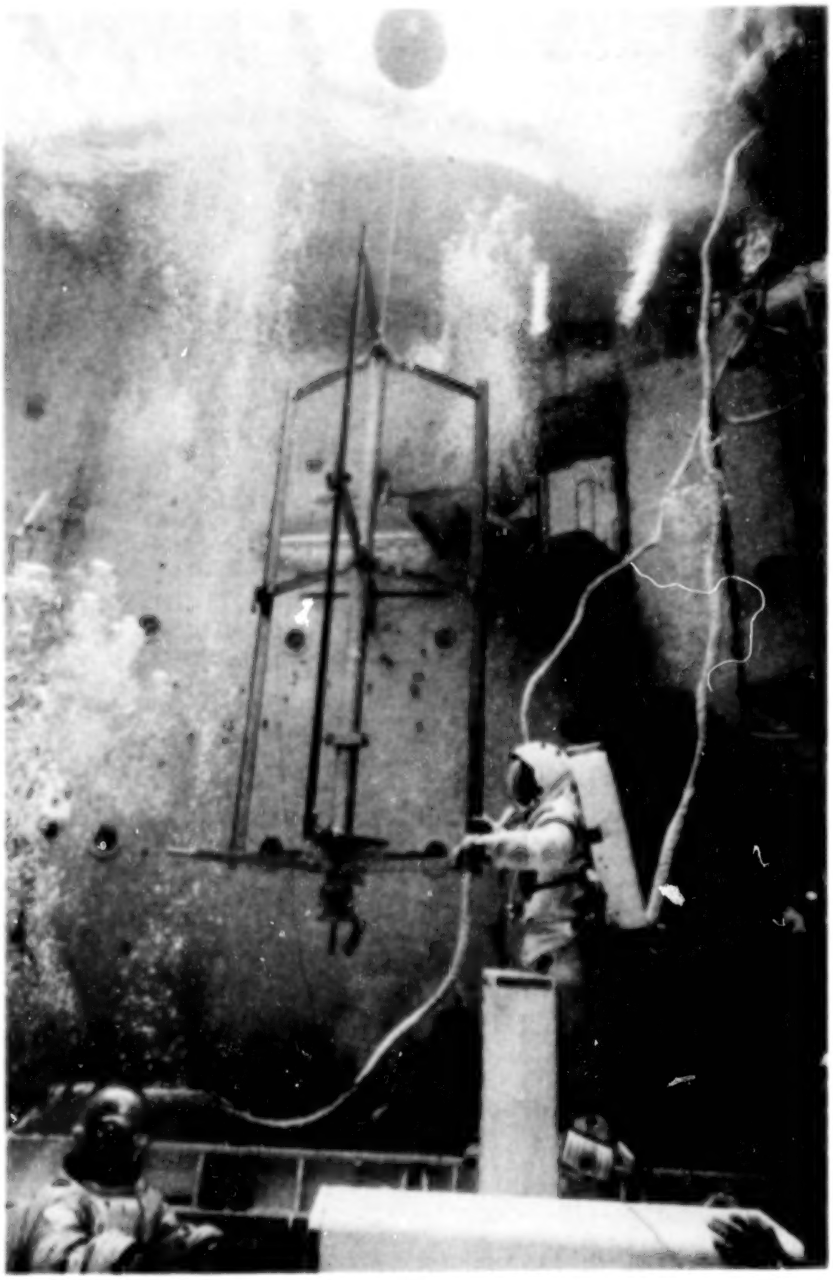
Safety is considered throughout the experiment development and integration process. Tests and analyses are used to verify that all hardware is safe for flight. The experiment developers provide data to the mission manager for their hardware. The mission manager compiles this data with data for the integration hardware into an integrated payload safety analysis which is presented to the STS safety panel for approval.

The safety process consists of analyzing each potential hazard and devising a solution to assure that the hazard cannot occur. Figure 5 identifies the steps of the safety process.

SAFETY PROCESS

- PHASE 0 – IDENTIFY POTENTIAL HAZARDS
- PHASE 1 – IDENTIFY APPROACHES TO ELIMINATE OR CONTROL HAZARDS
- PHASE 2 – VERIFY DESIGN, IMPLEMENT CONTROLS
- PHASE 3 – VERIFY HARDWARE AS BUILT, CERTIFY SAFETY COMPLIANCE

Each system that is potentially hazardous must be safe after any two failures. Some of the potential hazards analyzed for the EASE/ACCESS mission concerned structural failures caused by loads or stress corrosion; damage to the EVA suits by sharp edges; and electrical interference caused by static electricity. However, the most significant hazard addressed was the potential failure to disassemble the EASE or ACCESS structures which would prevent closing the payload bay doors. To preclude this hazard, two independent systems were designed to separate the assembled structures from the orbiter. Neutral buoyancy tests were performed to verify the operation of these contingency systems and to train the crew in their use. Figure 6 shows the crew exercising one of the ACCESS separation systems in the MSFC Neutral Buoyancy Simulator (NBS).



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An important element of the safety process is to verify that the payload is compatible with the Shuttle and the space environment. Early in the program, tests, analyses, and inspections are identified and scheduled to ensure safe and compatible interfaces. A verification plan is designed for each experiment and for Mission Peculiar Equipment.

The structural loads analysis is a critical part of the verification process. During the mission definition phase, each instrument developer is given design loads based on the past experience of similar hardware. After the hardware designs are completed, each developer provides a math model of their experiment to the mission manager for integration with other experiment math models. This math model for the integrated payload is supplied to JSC for simulation of launch and landing load conditions. Results of this simulation are compared with the design loads to verify adequate margins of safety.

A similar simulation was performed to determine loads imposed by the orbiter control system on the deployed EASE and ACCESS structures. This was required because the control system could excite resonant frequencies of the deployed structures with the possibility of causing structural failures. The results of this simulation imposed operating constraints on the orbiter during some of the experiment operations. The constraints prohibited the use of orbit controls during assembly and disassembly of the EASE experiment and during one part of the ACCESS experiment.

Some parts of the verification plan can be simplified if safety is not compromised. For example, the EASE/ACCESS payload was designed with flight approved materials and did not dissipate any energy as heat; therefore, a major integrated thermal analysis was not necessary. For most payloads, a thermal analysis using models of all of the payloads and the orbiter is performed to define the thermal environment for each payload and experiment.

The MSFC mission manager also performs safety analyses to ensure that the payload can be safely integrated and disassembled at KSC and that handling and testing equipment can be used safely. The results of these analyses are incorporated in the design of the flight hardware and ground support equipment and into the testing and handling procedures.

All payloads must comply with several established rules identified in the "Safety Policy and Requirements for Payloads Using the Space Transportation System", and the "STS Payload Ground Safety Handbook." Four safety reviews are held for flight safety and three are held for ground safety operations. The MSFC mission manager integrates the safety data provided by the instrument developers with the integrated payload analysis and presents it to the STS safety panel for final flight and ground safety certification. The payload must receive safety certification before it is delivered and integrated at KSC.

GROUND PAYLOAD PROCESSING

Ground payload processing occurs at the Kennedy Space Center were the payload elements are integrated on the carrier, checked out, and installed in the orbiter. The MSFC mission management team is responsible for developing the requirements and specifications which define payload processing at KSC. These requirements are documented in the Ground Integration Requirements Document. Typical requirements include off-line laboratory space and equipment for post-shipment tests by experimenters, procedures for attaching the experiments to the carrier, integrated checkout and verification tests, and envelope clearance tests for experiments. Requirements for interface tests, servicing, calibration, or special handling are specified.

The KSC integration team is in charge of payload processing; however, the MSFC mission management team and the experiment developers support these activities. After the payload is mechanically integrated, MSFC personnel and experimenters may participate in functional testing. For example, the integrated ACCESS structure was partially assembled to verify that the interfaces fit together properly. Other testing included inspections for sharp edges that might damage EVA suits and measurements to ensure proper clearance.

A Crew Equipment Interface Test (CEIT) was performed by the EVA crew to familiarize them with the flight hardware. For this test the astronauts remove each piece of hardware, examine it for fit and function, and return it to its launch configuration. A CEIT is required for payloads with extensive crew interfaces.

If a problem arises during integration, KSC issues a report describing the situation. Upon receiving the report, the MSFC management team meets with any involved parties to assess the problem. For example, during EASE/ACCESS integration, Kennedy personnel found a handrail that extended beyond the envelope for RMS clearance. The handrail had been added during experiment development to make it easier for the astronauts to get in and out of foot restraints. Since the handrail problem was discovered near launch time, MSFC, the experimenters, and JSC decided to remove the handrail rather than modify the hardware.

As the payload is processed, MSFC and KSC personnel may hold formal meetings to discuss any outstanding situations that need resolution. Crew training and experiment procedures are usually underway simultaneously with payload processing. The management team may decide to modify the integration plan as a result of a discovery during crew training. For example, during EASE/ACCESS neutral buoyancy tests, it became apparent that a foot restraint needed to be moved for easier handling of equipment. To make these kinds of modifications, MSFC prepares a modification kit to be installed by KSC personnel.

FLIGHT PLANNING

The MSFC mission management responsibility also includes developing plans for inflight activities that support payload operations. For partial payloads, JSC is responsible for creating a plan that outlines all flight activities. This plan is based on inputs from MSFC and other organizations with payloads assigned to the flight.

Some of this information is available in the Experiment Requirements Document input by the investigators. Other data are identified during development testing like that done for EASE/ACCESS in the MSFC Neutral Buoyancy Simulator. For EASE/ACCESS, MSFC provided JSC with information such as the number of EVAs required for assembly, the number of assemblies and disassemblies of each structure required to gather data on human performance during space construction, the approximate time needed for each assembly, the number of EVA crew members required for each task, and the length of each EVA.

The mission management team provided JSC with step-by-step descriptions of crew tasks. For EASE/ACCESS, MSFC provided input into the EVA annex describing all operations during the two six-hour EVAs and payload flight data files with procedures for assembly and disassembly of the structures as well as data collection. Procedures to solve possible contingencies were also outlined. Working with the experimenters, MSFC decides which tasks have the highest priority in case an EVA or the mission ends early. Using all this data, JSC can write flight rules, develop a detailed Crew Activity Plan for the entire mission, and decide which tasks have priority. Before the mission, flight rules are written for potential malfunctions so that decisions can be made expediently on-orbit.

The MSFC management team also carefully plans flight payload operations support activities that take place on the ground. Before the mission, key personnel and their responsibilities are defined. The EASE/ACCESS team worked in the Customer Support Room (CSR) at JSC and in the Huntsville Operations Support Center (HOSC) at MSFC.

There must be a mutual understanding between the STS flight operations staff and the teams supporting various payloads. For EASE/ACCESS, JSC personnel communicated directly with the crew, and the MSFC mission manager communicated with the Johnson EVA officer via a voice loop. Other key personnel such as EASE/ACCESS experimenters and MSFC engineers who wrote assembly procedures or designed hardware served as technical advisors during the mission.

Two to three months before a mission, planning for inflight and ground operations culminate in joint integrated mission simulations in which crucial segments of the mission are rehearsed. These serve to train both the astronauts and the flight operations support crew and to identify any unresolved problems. For EASE/ACCESS, EVA activities were practiced with the astronauts assembling and disassembling the structures in the JSC Weightless Environment Training Facility while JSC and MSFC personnel performed their roles from the JSC Mission Control Center (MCC) and CSR and the MSFC HOSC.

The result of these flight planning activities was smooth on-orbit operations during the EASE/ACCESS experiments. Both experiment teams gathered data beyond their mission objectives. After the mission, the MSFC mission management team continued to support postflight activities, such as crew debriefings. The EASE/ACCESS hardware was deintegrated at KSC and returned to the appropriate organizations.

SUMMARY

The mission management and integration activities were carried out successfully for the EASE/ACCESS mission. This means that the payload was compatible with the orbiter interfaces; the payload operated safely; and the experiment requirements were fully satisfied. These efforts were accomplished within the cost and schedule originally established for the project.

Costs were minimized by using available hardware and an established mission integration process. The structural carrier used for EASE/ACCESS was the Mission Peculiar Equipment Support Structure (MPESS), which was available in the existing hardware inventory. In addition, standard STS hardware such as the CCTV, movie and still film cameras, and video recorders was used for data collection.

With the exception of designing the crew interfaces for extravehicular activities (EVAs), the mission management and integration of EASE/ACCESS was accomplished using methods developed for previous missions. Missions such as OSTA-2 and OAST-1 were simple payloads which utilized the MPESS in a manner similar to EASE/ACCESS. However, the extensive crew involvement in EVAs and the tests in the MSFC Neutral Buoyancy Facility were unique aspects of the mission. It is the purpose of this paper to make others aware of the experience gained on this mission in hope that it will be of benefit in planning future space construction missions involving EVA.

N88-10876

A MONOGRAPH OF THE NATIONAL SPACE TRANSPORTATION SYSTEM OFFICE (NSTSO) INTEGRATION ACTIVITIES CONDUCTED AT THE NASA LYNDON B. JOHNSON SPACE CENTER FOR THE EASE/ACCESS PAYLOAD FLOWN ON STS 61-B

Charles Chassay
National Space Transportation System Office
NASA Lyndon B. Johnson Space Center
Houston, Texas

Space Construction Conference
NASA Langley Research Center
August 6 and 7, 1986

ABSTRACT

The integration process of activities conducted at the NASA Lyndon B. Johnson Space Center (JSC) for the experimental assembly of structures in extravehicular activity (EASE)/assembly concept for construction of erectable space structures (ACCESS) payload is provided as a subset to the standard payload integration process used by the NASA Space Transportation System (STS) to fly payloads on the Space Shuttle. The EASE/ACCESS payload integration activities are chronologically reviewed in this paper beginning with the initiation of the flight manifesting and integration process. The development and documentation of the EASE/ACCESS integration requirements are also discussed along with the implementation of the mission integration activities and the engineering assessments supporting the flight integration process. In addition, the STS management support organizations, the payload safety process leading to the STS 61-B Flight Certification, and the overall EASE/ACCESS integration schedule are presented.

INTRODUCTION

The role played by JSC in the integration of the EASE/ACCESS payload was to document and coordinate the implementation of the payload technical and scientific requirements. This effort was the responsibility of the National STS Office (NSTSO) with other JSC organizations furnishing various levels of technical and operational support during the preflight integration, flight, and postflight periods. This paper is a summary of the participation by JSC in the total integration process for EASE/ACCESS payload. Details of specific integration support activities, such as training and crew activities, and associated results appear elsewhere in other papers and discussions presented at this conference.

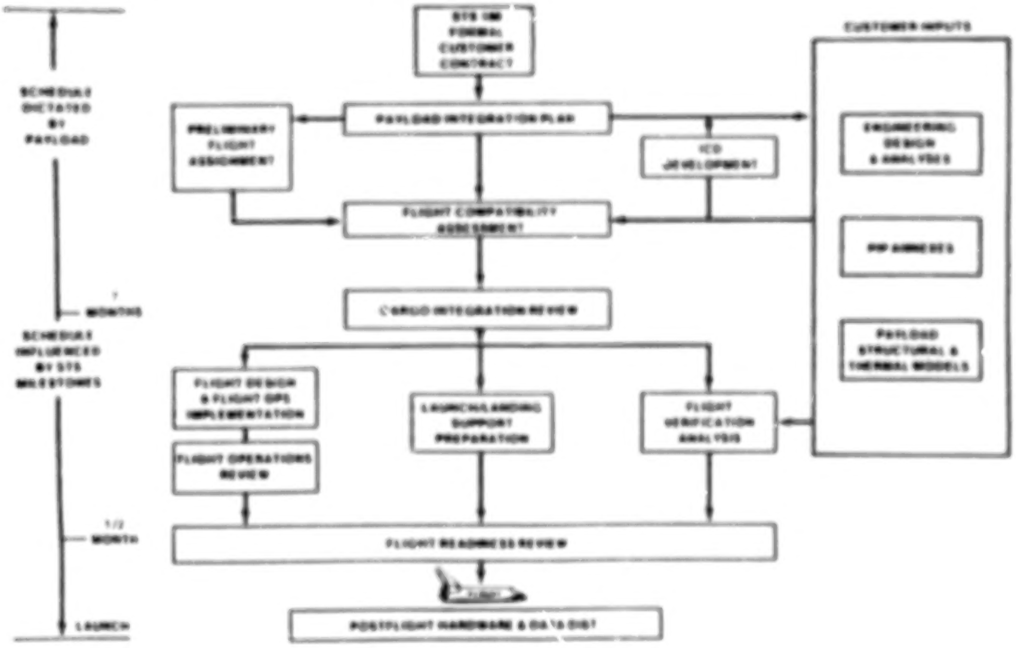
THE STS INTEGRATION FLOW FOR THE EASE/ACCESS PAYLOAD

On December 14, 1983, the NSTSO at JSC received from NASA Headquarters a memorandum and the EASE/ACCESS Request for Flight Assignment Form (NASA STS Form 100) authorizing the technical payload integration process to begin. The Headquarters Customer Services Office memorandum containing the NASA STS Form 100 was also forwarded to NASA John F. Kennedy Space Center (KSC), advising KSC payload integration personnel to also prepare for the technical integration of the EASE/ACCESS payload. Upon receipt of the EASE/ACCESS NASA STS Form 100 at JSC, the Flight Assignment Working Group (FAWG) began investigating manifesting opportunities for a flight for the EASE/ACCESS payload. The NASA STS Form 100 requested that EASE/ACCESS be manifested on a specific flight (STS-25) in the summer of 1985. Because of numerous manifesting problems (e.g., satellite deployment failures on STS 41-B and 51-D, satellite retrieval mission priorities on STS 51-A and 51-I, etc.) the EASE/ACCESS payload was preempted from its originally requested flight and finally manifested on STS 61-B (STS-31 under the previous STS accountability system for numbering space flights). The flow of the EASE/ACCESS payload integration activities at JSC started with the receipt of the NASA STS Form 100 and can be followed on the overview chart shown in Figure 1.

After having received the EASE/ACCESS NASA STS Form 100 at JSC, the NSTSO management assigned the author of this paper as the Payload Integration Manager (PIM) for the EASE/ACCESS payload. The PIM served as the primary technical point of contact for the NASA George C. Marshall Space Flight Center (MSFC) Spacelab Payload Program Office (SPPO) throughout the integration process, from the initial contact meeting, during the flight, and through postflight activities. The PIM was responsible for ensuring the technical requirements had been accurately defined and documented, were compatible with the Orbiter's payload accommodations, and were properly implemented. The author also served as coordinator for all payload engineering and other technical support activities which were required to integrate the EASE/ACCESS payload at JSC.

Technical integration of the EASE/ACCESS payload began with an introductory NSTSO payload integration meeting conducted with MSFC SPPO personnel at JSC on January 26, 1984. Key flight operations and engineering personnel from the NSTSO, and from other organizations that support the STS payload integration process, discussed and negotiated the technical integration requirements for EASE/ACCESS. All of the technical requirements and agreements required to integrate the payload into the STS were documented in the EASE/ACCESS Payload Integration Plan (PIP), JSC 18436. As part of the EASE/ACCESS PIP, an integrated STS/payload schedule was negotiated and agreed to. The dates when major STS integration milestones were achieved and when EASE/ACCESS integration documentation was baselined are shown in Figure 2. Additional detailed requirements and agreements, including the EASE/ACCESS launch and landing site requirements, are documented in the EASE/ACCESS seven annexes (annexes 1, 2, 3, 6, 7, 8, and 11) to the EASE/ACCESS PIP. A brief summary of the content of each of these annexes

PAYLOAD INTEGRATION PROCESS OVERVIEW


STS OR FORMAL CUSTOMER CONTRACT
CUSTOMER INPUTS
SCHEDULE DICTATED BY PAYLOAD
PRELIMINARY FLIGHT ASSIGNMENT
PAYLOAD INTEGRATION PLAN
ICD DEVELOPMENT
ENGINEERING DESIGN & ANALYSES
FLIGHT COMPATIBILITY ASSESSMENT
PIP ANNEXES
7 MONTHS
CARGO INTEGRATION REVIEW
SCHEDULE INFLUENCED BY STS MILESTONES
PAYLOAD STRUCTURAL & THERMAL MODELS
FLIGHT DESIGN & FLIGHT OPS IMPLEMENTATION
LAUNCH/LANDING SUPPORT PREPARATION
FLIGHT VERIFICATION ANALYSIS
FLIGHT OPERATIONS REVIEW
1/2 MONTH
FLIGHT READINESS REVIEW
LAUNCH
POSTFLIGHT HARDWARE & DATA DIST

is discussed in the following paragraphs. Although documented separately, these annexes are considered an extension of the payload technical requirements definition and are considered an adjunct to the approved EASE/ACCESS PIP.

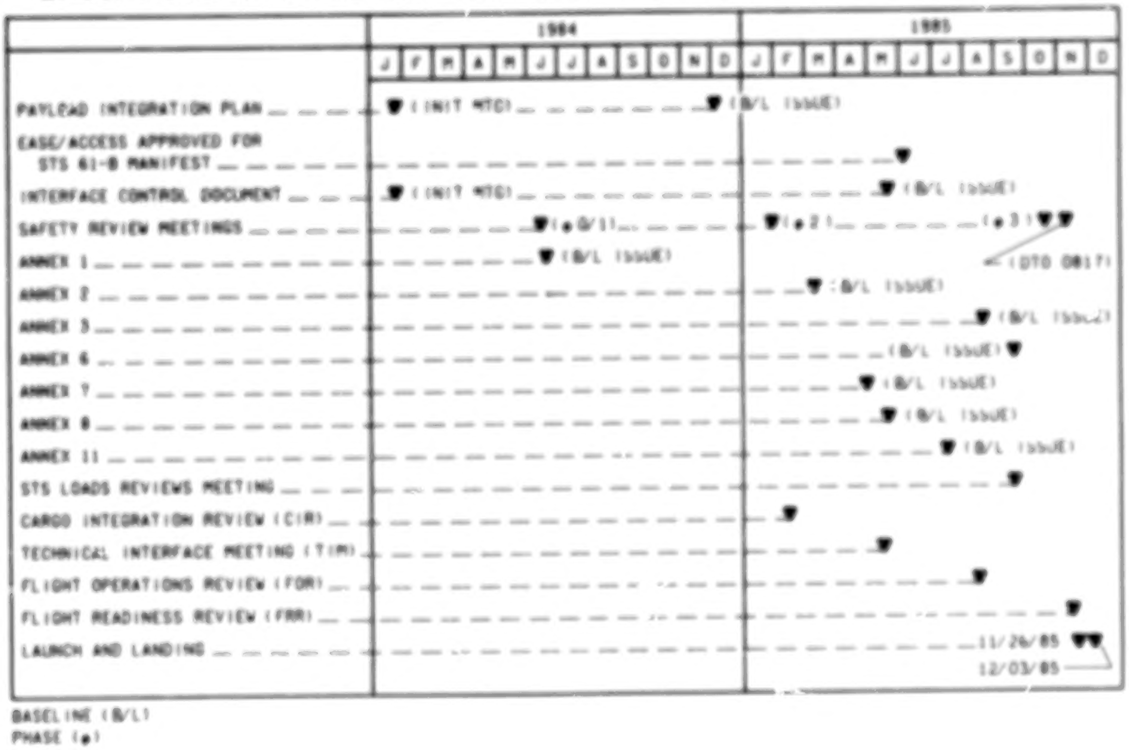
ANNEX 1 - PAYLOAD DATA PACKAGE

The Payload Data Package Annex provided detailed data on the physical characteristics of the EASE/ACCESS payload including defined weights, center of gravity data, sequenced mass properties, and the configuration and dimensional data of the payload in both the stowed and erected configurations for the EASE and for the ACCESS experiments.

ANNEX 2 - FLIGHT PLANNING

The Flight Planning Annex contained the required flight design and crew activity requirements for the EASE/ACCESS payload. The annex comprised two sections: the flight design section containing information on Orbiter equipment usage such as still and motion cameras, remote manipulator system (RMS) video system, cargo bay lights, one aft and two forward cargo bay closed circuit television (CCTV) cameras, and three aft flight deck CCTV video tape recorders (VTR's). The flight activities planning section contained payload scheduling data which was used to develop the STS 61-B Crew Activity Plan (CAP) and included EASE/ACCESS experiment timeline data, EASE/ACCESS payload scheduling constraints, and crew payload support requirements.

EASE/ACCESS PAYLOAD INTEGRATION ACTIVITIES SCHEDULE



ANNEX 3 - FLIGHT OPERATIONS SUPPORT

The Flight Operations Support Annex documented the SPPO inputs for on-orbit EASE/ACCESS payload flight control operations and procedures. Specifically covered were the EASE/ACCESS payload operations support plan, the payload flight operations decisions, payload operations procedures, payload malfunction procedures including contingency jettison, and the EASE/ACCESS science data collection requirements and constraints.

ANNEX 6 - ORBITER CREW COMPARTMENT

The Orbiter Crew Compartment Annex provided a detailed description of the EASE/ACCESS payload items to be installed in the Orbiter crew compartment. The equipment description included individual part numbers, quantities, size, weight, and usage requirements of the EASE/ACCESS hardware items which affected its crew compartment stowage location, crew physical access, and the crewmember handling of the equipment.

ANNEX 7 - TRAINING

The Training Annex documented a training schedule and a description of the payload-unique EASE/ACCESS payload training activities. It included the EASE/ACCESS training that the SPPO required of the STS mission specialists and the training required to satisfy the SPPO payload experimenter science requirements. These EASE/ACCESS training requirements were integrated with the Space Shuttle specific premission training activities to schedule the EASE/ACCESS payload training when STS crewmembers were available.

ANNEX 8 - LAUNCH SITE SUPPORT PLAN (LSSP)

The Launch Site Support Plan Annex contained data for planning launch site processing of the EASE/ACCESS payload. The plan was a commitment of launch site facilities, support equipment, and services to the SPPO for a given time period to conduct assembly, test, and checkout of the EASE/ACCESS payload. A KSC Launch Site Support Manager (LSSM), assigned to the EASE/ACCESS payload, prepared the LSSP after having received the MFSC-SPPO-provided EASE/ACCESS Ground Integration Requirements Document (GIRD) and after coordinating and negotiating the requirements documented in the LSSP with the SPPO.

ANNEX 11 - EXTRAVEHICULAR ACTIVITY (EVA)

The Extravehicular Activity Annex defined the payload-unique EVA interface requirements for both planned and contingency EASE/ACCESS flight operations. The EASE/ACCESS requirements included a definition of all physical, functional, and environmental interfaces. Physical interface data for the EASE/ACCESS payload consisted of items such as payload and experiment geometry, hardware dimensions, EASE/ACCESS placement location in the Orbiter cargo bay, payload equipment weights, forces, etc. Functional data included both EASE and ACCESS experiment task definition and time requirements. The EASE/ACCESS environmental interface data documented such things as thermal surface temperature constraints, Orbiter vehicle orientation constraints, etc. Also included in the EVA Annex was information on EVA crewmembers translation paths, crew worksite interface requirements, EASE/ACCESS payload contingency jettison, payload markings and decals, cargo bay EVA support equipment stowage for the EASE/ACCESS payload, and the mission scenarios for both EVA's.

Once the technical integration requirements and agreements had been reviewed, negotiated, and agreed to by both the SPPO and the NSTSO, the EASE/ACCESS PIP became the overall payload technical requirements contract. The development process for the documentation of the detail requirements in the EASE/ACCESS PIP annexes was different from the PIP development process in that the MSFC SPPO provided the initial data submittal of the preliminary EASE/ACCESS annexes which were then reviewed by various designated STS PIP annex managers. The EASE/ACCESS annex managers separately negotiated each annex, fitting the EASE/ACCESS payload science and technical requirements to STS capabilities. The EASE/ACCESS PIP annexes were formally baselined (exception - annex 8) in the same manner as the EASE/ACCESS PIP and represented part of the STS-to-EASE/ACCESS technical contract. Once signed and baselined, all subsequent changes to either the EASE/ACCESS PIP or to the PIP annexes were then covered by STS configuration management control (exception - annex 8). All technical changes were formally submitted to the JSC NSTSO Mission Integration Configuration Review Board. Approval of either EASE/ACCESS PIP or PIP annex technical changes by both the MSFC SPPO and the STS management at JSC was required prior to change implementation by the STS.

The EASE/ACCESS integration process also included payload interface discussions and negotiations of the payload-to-STS physical interface definition, EASE/ACCESS payload flight interface loads, and EASE/ACCESS equipment clearances. The first interface discussions were initiated in a meeting on January 27, 1984, the day following the initial EASE/ACCESS PIP meeting. Conducting a payload-to-STS Interface Control Document (ICD) meeting prior to the signing and baselining of the EASE/ACCESS PIP was employed as a trial method for initiating ICD activities with future STS payloads. Although this early start for the development of the EASE/ACCESS ICD was successful, the concept of early initiation for preparation of ICD's is no longer used by the NSTSO for cargo bay payload ICD development. At present, all cargo bay STS-to-payload ICD discussions and related activities are initiated only after the specific payload technical requirements are well understood and agreed to (e.g., after the payload PIP has been signed). The EASE/ACCESS ICD was subsequently signed and baselined on May 23, 1985.

In addition to the standard cargo bay STS-to-payload interfaces, the EASE/ACCESS extravehicular activity (EVA) STS 61-B mission required unique tools to be used in support of both the EASE and the ACCESS experiments. These tools were stowed in the Orbiter provisions stowage assembly (PSA) containers located in the cargo bay. The stowage allocation for the EASE/ACCESS tools on the STS 61-B mission was negotiated between the NSTSO and the STS Orbiter and Government Furnished Equipment (GFE) Project Office, and documented in a formal Change Request (G-1635, approved July 8, 1985) presented to the JSC Orbiter Flight Equipment Configuration Management Review Board. The method and stowage location of the EASE/ACCESS tools were documented on the STS 61-B Mission PSA Assembly Drawing (M072-661633-020) and were not included as part of the EASE/ACCESS ICD-A-18436.

Further, EASE/ACCESS payload crew cabin stowage was also utilized to stow the extensive amount of video cassette, photographic film, and camera equipment required to document the EASE/ACCESS scientific data collected during the two STS 61-B EVA's. Two stowage lockers in the Orbiter crew compartment middeck were allocated to accommodate all of the EASE/ACCESS cassette, film, and camera equipment stowage. The EASE/ACCESS stowage locker allocation was used to stow 57 CCTV video cassette tapes (1 additional cassette tape was stowed inside each of the 3 dedicated video tape recorders), 6 rolls of 16 mm movie film, 1 role of 70 mm film and miscellaneous ancillary camera equipment items.

During the PIP and PIP annex development process, the safety process for the EASE/ACCESS payload was concurrently being developed. It is the responsibility of the STS to establish the safety requirements for all flight payloads and to ensure that all payload safety hazards identified by the customer are properly controlled to meet the established STS safety requirements. Safety is of paramount importance to the STS and is an ongoing iterative process that is integral to all payload/STS integration activities. The following reference documents define the ground and the flight technical and system safety requirements for the EASE/ACCESS payload.

Space Transportation System Payload Ground Safety Handbook, KHB 1700.7

Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), NHB 1700.7A

Implementation Procedure for STS Payloads System Safety Requirements, JSC 13830A

STS Payloads Safety Guidelines Handbook, JSC 11123

Interpretations of STS Payload Safety Requirements, JSC 18798

The beginning of JSC's involvement with the EASE/ACCESS payload safety activities was initiated with a payload conceptual design meeting held at JSC on December 7, 1982. The meeting was held to discuss EASE/ACCESS physical design and operational concepts with safety, astronaut, payload program office, mission operations, and training personnel. Equipment failures that could cause in-flight hazards or safety concerns with the payload were discussed and proposed solutions were provided to the EASE/ACCESS experiment hardware design team to explore during development of their payload. Also included in the discussion was the methodology of a payload component jettison should failure of an EASE/ACCESS component preclude its safe stowage for Orbiter landing. Although the meeting was not considered part of the formal payload process, it did result in safety-related operational and design agreements which served to establish, in part, the basis for the formal EASE/ACCESS payload safety data package submittal from the MSFC SPPO.

The EASE/ACCESS payload safety program was the responsibility of the SPPO and, to this extent, the SPPO was responsible for ensuring that the EASE/ACCESS hardware, including the ground support equipment (GSE), complied with the requirements stated in the previously listed safety documents. This responsibility included the identifying, reporting, and resolving of any possible EASE/ACCESS safety hazards, as well as certifying preflight to the STS 61-B Flight Readiness Review (FRR) Board that the EASE/ACCESS payload was safe to install into the Orbiter and to fly on that mission.

The JSC Safety Review Panel, made up of both technical and operational personnel from disciplines such as mission operations, Orbiter payload integration, payload safety, engineering, ground operations, and life sciences, conducted all three of the phased EASE/ACCESS flight safety reviews. During the reviews all aspects of the payload equipment design and flight operations were reviewed. The depth and number of formal safety reviews for the EASE/ACCESS payload were determined by the STS Safety Review Panel chairman in conjunction with the mission manager from the SPPO and depended on the potential and complexity of the safety hazards involved and the technical maturity of the SPPO safety documentation to support control and closure of the EASE/ACCESS hazards. The date of occurrence and the primary objectives of each of the EASE/ACCESS safety reviews were as follows.

PHASE	DATE	REVIEW OBJECTIVES
0/1	6/19/84	To identify all EASE/ACCESS safety-critical hazards and applicable safety requirements for subsystems, to assess the implementation approach to each hazard control along with the development of an understanding of verifying the approach by the SPPO for the control of each of the EASE/ACCESS hazards.
2	1/31/85	To verify the EASE/ACCESS payload design compliance with the safety hazard requirements and review each of the SPPO hazard verification methods.
3	10/23/85*	To review all of the EASE/ACCESS hazards, to ensure completion of all SPPO safety verification activities, and to agree that all safety activities for the EASE/ACCESS payload have been satisfactorily completed.

* The MSFC SPPO EASE/ACCESS payload safety package data submittal was reviewed by the JSC Payload Flight Safety Panel without conducting a formal meeting. The date shown reflects the formal Phase 3 safety approval by the JSC Safety Panel in an NSTSO letter to the MSFC SPPO agreeing that control and closure of all EASE/ACCESS flight hazards had been satisfactorily accomplished by the SPPO.

The JSC Orbiter and GFE Project Office provided the Certification of Flight Safety and Readiness for the stowage of the EASE/ACCESS support tools and equipment in the STS 61-B mission cargo bay PSA's.

To support the implementation of the EASE/ACCESS PIP requirements and the safety development process a number of specific engineering assessments were conducted by the STS on the EASE/ACCESS payload. Summary information for each of the engineering assessments is listed as follows.

C-2

THERMAL ASSESSMENT

Because the EASE/ACCESS payload had no electrical-heat-generating equipment, only a minimal thermal engineering assessment was conducted by the STS on the EASE/ACCESS payload. The purpose of the assessment was to ensure that the known design surface properties of the EASE/ACCESS payload components would not exceed a safe touch temperature for the EVA crewmembers during EASE/ACCESS activities. For the STS 61-B mission, the Space Shuttle thermal working group did conduct an integrated STS/payload thermal assessment on the combined effects of all the payloads in the cargo bay using payload-supplied thermal data in place of a completely integrated STS/payload mission analysis.

STRUCTURAL ASSESSMENT

An STS structural loads assessment was conducted for the EASE/ACCESS payload for its specific STS 61-B cargo bay location. The STS assessment was based on various dynamic transient and quasi-static load conditions of the Space Shuttle. The structural assessment was completed using a structural loads math model of the EASE/ACCESS payload in the stowed position; the math model had been provided to the STS by the SPPO. The STS used a coupled loads analysis for the STS 61-B cargo mix to determine the maximum expected flight interface loads and relative deflections for the various load conditions. The EASE/ACCESS payload was required to be compatible with the resulting loads and deflections. An STS 61-B Loads Verification Review was conducted by the Space Shuttle structural working group with EASE/ACCESS personnel on September 26, 1985, to review the structural compatibility of all of the STS 61-B cargo bay payloads.

ELECTROSTATIC CHARGE ASSESSMENT

On each of the two STS 61-B EVA's, the crewmembers were to assemble and disassemble EASE/ACCESS components which were made of different interface surface material compositions. NSTSO management personnel expressed a safety concern that the potential for an electrostatic charge buildup on the component frictional interfaces could occur, and, in combination with a hydrogen leak in the cargo bay during the reentry and landing phase, may be sufficient to cause an explosive situation to occur. Therefore, the potential for an electrostatic charge accumulation during EASE/ACCESS on-orbit activities was assessed in detail. It was determined from the assessment that, because of a lack of a credible charging mechanism, only an extremely small charge potential could be built up by the crewmembers during the EVA's from the friction between the EASE/ACCESS components moving relative to one another and that it produced insufficient arc potential for an inflight hazardous condition to occur.

VIDEO TAPE RECORDER ASSESSMENT

Because of the lengths of constant on-time that the Orbiter VTR's were scheduled to operate during each of the two planned EVA's, an assessment was made to see if VTR's available from previous mission accommodations could be used to support the EASE and the ACCESS data collection along with the STS-required EVA egress and ingress overhead recording times. The assessment concluded in summary that because of their design, the operation of the three VTR's required to support EASE/ACCESS data collection may become marginal at the end of each of the two mission EVA's. The decision by both the SPPO and NSTSO personnel to accept the minimal risk was based primarily on not having any acceptable flight qualified VTR's to use as substitutes on the STS 61-B flight, and the development time and costs associated with qualifying new VTR's.

ON-ORBIT FLIGHT CONTROL/INDUCED LOADS ASSESSMENT

JSC, with the responsibility for flight control activities, made a study to investigate the interaction between the EASE and the ACCESS erected structures and the on-orbit control of the Space Shuttle Orbiter. The study was performed by the Charles Stark Draper Laboratory, Inc. of Cambridge, MA, for JSC using a computerized simulation containing the Space Shuttle Orbiter flight control model and the structural math models of both the EASE and the ACCESS experiment hardware in their fully erected stages. Both the EASE and the ACCESS math models were provided to Draper Labs by the MSFC SPPO. The results of the study were used to develop several of the STS 61-B mission flight rules, specifically those flight rules protecting the Space Shuttle Orbiter during the on-orbit period of EASE/ACCESS payload activities. The use of the flight rules served as hazard controls to preclude exposing the crew and the Orbiter to hazardous conditions in flight which may have developed from excessive flight control induced loads on the erected experiments during the EASE/ACCESS payload activities.

COMPUTERIZED VIEWING ASSESSMENT

To assure adequate equipment clearances for the crew during the EASE/ACCESS EVA operations and for the EASE/ACCESS scientific data collection, a computer aided design/computer aided engineering (CAD/CAE) Orbiter cargo bay camera assessment was conducted. The CAD/CAE data provided prospective computerized displays of the EASE/ACCESS payload and the EVA crewmembers from the various Orbiter camera locations, simulating photographic and CCTV data collection through the Orbiter aft flight deck windows and from the cargo bay bulkhead and RMS cameras. Simulations of minimum and maximum viewing angles from the cameras including zooming capability for the various camera lens systems planned for use on the STS 61-B flight were performed. Simulated views looking at the EVA crewmembers hands, patches placed on the crewmembers EVA suits, and for the EVA crewmembers at each of the EASE/ACCESS permanent workstations and in the manipulator foot restraint (MFR) were provided to the SPPO to augment their hardware design. In addition, the CAD/CAE simulated EASE/ACCESS payload movement in the Orbiter cargo bay to see if conflicts in camera viewing existed while the EVA crewmembers were accomplishing the EASE/ACCESS activities.

CARGO ENGINEERING ASSESSMENT

In support of the STS verification of a customer's documented requirements, a cargo engineering assessment was made prior to the formal Cargo Integration Review (CIR) for the mission. This engineering assessment is performed by various NASA JSC and KSC organizations and by the JSC payload integration support contractor, Rockwell International, of Downey, CA. The payload documentation inputs and organizations that participate in the integrated mission cargo engineering assessment and the flight products produced as a result of the integrated cargo assessment are shown in Figure 3. The results of the cargo engineering assessment determined the compatibility of the EASE/ACCESS payload with the Orbiter and other payloads on board the STS 61-B flight. Following this assessment, cargo engineering drawings and documents called flight products were finalized, signed, and placed under configuration management control. The mission flight products were assessed for all payloads and included specific information on EASE/ ACCESS payload specific installation drawings and removal instruction details, EASE/ACCESS-to-Orbiter integration hardware, EASE/ACCESS integration hardware placement and definition, and any other products required to implement the cargo manifest and to ensure cargo compatibility.

In addition to the various engineering assessments conducted to validate the EASE/ACCESS integration activities into the STS, the EASE/ACCESS payload required further integration support activities to ensure that the science data requirements could be accommodated. Selection of the cargo bay CCTV camera lens for each of the cameras was reviewed to ensure an acceptable compatibility with all mission requirements. Because the JSC Orbiter and GFE Project Office were qualifying a new 16 mm movie camera system for flight, the EASE/ACCESS requirement to have stereoscopic viewing by two synchronized 16 mm movie cameras was added to the purchase of new flight cameras being procured by the STS. The camera changes such as shutter lens modification, synchronization of camera frames between two cameras, and applying a time code of HR/MIN/SEC to each film frame were successfully completed and tested. A test of the modified camera system was conducted in the JSC one-g flight trainer to verify camera synchronization operations and film exposure prior to the mission to ensure compatibility with EASE/ACCESS science requirements.

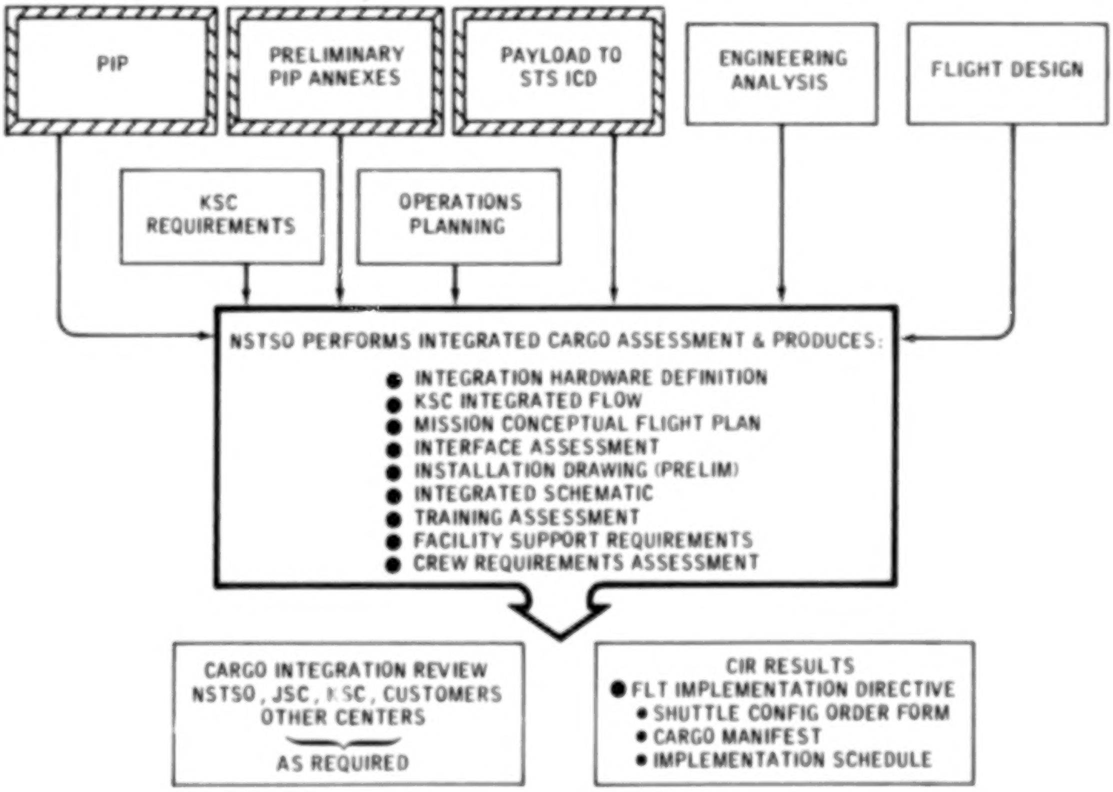

PIP
PRELIMINARY PIP ANNEXES
PAYLOAD TO STS ICD
ENGINEERING ANALYSIS
FLIGHT DESIGN
KSC REQUIREMENTS
OPERATIONS PLANNING
NSTSO PERFORMS INTEGRATED CARGO ASSESSMENT & PRODUCES:
● INTEGRATION HARDWARE DEFINITION
● KSC INTEGRATED FLOW
● MISSION CONCEPTUAL FLIGHT PLAN
● INTERFACE ASSESSMENT
● INSTALLATION DRAWING (PRELIM)
● INTEGRATED SCHEMATIC
● TRAINING ASSESSMENT
● FACILITY SUPPORT REQUIREMENTS
● CREW REQUIREMENTS ASSESSMENT
CARGO INTEGRATION REVIEW
NSTSO, JSC, KSC, CUSTOMERS
OTHER CENTERS
AS REQUIRED
CIR RESULTS
● FLT IMPLEMENTATION DIRECTIVE
• SHUTTLE CONFIG ORDER FORM
• CARGO MANIFEST
• IMPLEMENTATION SCHEDULE

Figure 3

The EASE/ACCESS science data were collected on Eastman Kodak 5017 ASA64 photographic film from an STS version of a 70 mm Hasselblad model 500 ELM camera. CCTV tapes were 3/4-inch U-Matic format cassette tapes and the 16 mm movie film was Eastman Kodak 852 ASA 400 thin base color film used in the two modified Arriflex model 16 SRII cameras. For the 16 mm movie film photography tradeoffs such as the types of film to be used versus modified camera lens system for Orbital day/night exposure cycles versus available STS GFE camera lens systems were performed to provide optimum EASE/ACCESS photographic science data collection.

The total amount of still and movie film, CCTV cassette tapes, and the ancilliary camera equipment used to document the EASE/ACCESS scientific data were agreed to and documented in the EASE/ACCESS PIP and the EASE/ACCESS Crew Compartment Annex (annex 6). The postflight EASE and ACCESS experiment photography, CCTV cassettes, film and color conversion requirements, and the product delivery requirements requested by the MSFC SPPO were documented in a letter from the SPPO to the JSC Photographic Laboratory.

EASE/ACCESS crew training for the STS 61-B mission is the subject of another paper to be presented in detail at this conference. It is appropriate to mention in summary that a major portion of the preflight procedure development and EVA crewmember training on the EASE/ACCESS payload did occur at the MSFC during three EASE/ACCESS neutral buoyancy tests. NSTSO programmatic support for the EASE/ACCESS tests consisted of providing direction and requirements to the JSC Orbiter and GFE Project Office to ensure that the necessary JSC technical personnel and properly configured equipment participate in each of the three MSFC tests before, during, and after the STS 61-B flight crew training.

With the completion of the development and the agreement of the EASE/ACCESS flight, training, and mission support requirements, formal verification of the requirements was performed through participation by the MSFC SPPO personnel in several formal STS reviews. A summary of each of these reviews is subsequently presented.

The EASE/ACCESS payload interface compatibility and the operational and safety requirements were verified at several STS Cargo Integration Reviews (CIR's) prior to the final manifesting assignment on STS 61-B. Because EASE/ACCESS was considered a somewhat inert payload (e.g., no power, cooling, or data requirements) and had been fully assessed in previous CIR reviews, the NSTSO made the decision not to hold another CIR or a Delta CIR on the STS 61-B mission after the flight manifest had been changed to include the EASE/ACCESS payload. Instead, a formal configuration change directive was reviewed and approved by STS personnel and was sent by the NSTSO to all JSC and KSC STS support organizations defining the overall cargo mission requirements and the scenario of the planned STS 61-B flight activities. The STS 61-B cargo complement and the cargo bay flight payload configuration are shown in Figure 4. The STS support organizations that had previously provided CIR assessments on the EASE/ACCESS payload requirements incorporated the EASE/ACCESS requirements into the STS 61-B flight products and proceeded to develop the necessary flight implementing documentation required to support the STS 61-B mission. The STS change directive provided the proper authorization for the STS 61-B cargo mix changes, and a normal review and engineering release process for the STS 61-B flight products followed. Typically the Cargo Integration Review

(CIR) is the first of the payload requirements verification reviews in which a customer participates. The CIR's are conducted to ensure that all mission payloads can physically and functionally be integrated into a flight which is within the STS flight and ground capabilities. The CIR establishes the baseline of the flight event sequence and provides the payload organizations an opportunity to review their payload requirements at the cargo/flight level. The typical flow of cargo compatibility activities leading to the CIR and the implementing authorization are summarized in Figure 3. The individual mission CIR's are chaired by the NSTSO manager at JSC with board members from the STS elements and the payload customers. The results of the CIR provide the implementing organizations with the basic engineering, operations, and support baseline to initiate the flight and ground implementing activities.

A payload technical interface meeting (TIM) was held on May 16 and 17, 1985, to review the EASE/ACCESS operation annexes (annexes 3 and 11) and the training annex (annex 7). Also included in the agenda were detailed discussions of the STS camera configuration, the EASE/ACCESS photography scene requirements, and the types and quantity of film to be used to collect the science data for both the EASE and the ACCESS experiments. The RMS support requirements and the EASE/ACCESS Space Station Assembly Test Detail Test Objective (DTO 0817) were also discussed in detail. Persons attending the meeting included the experiment principal investigators for both the EASE and ACCESS experiments and their associated management and technical personnel from the MSFC SPPO, Langley Research Center, and the Massachusetts Institute of Technology. JSC was represented by personnel from the operations and training divisions, the STS 61-B flight crew, camera and RMS equipment systems managers, and the NSTS Program Office.

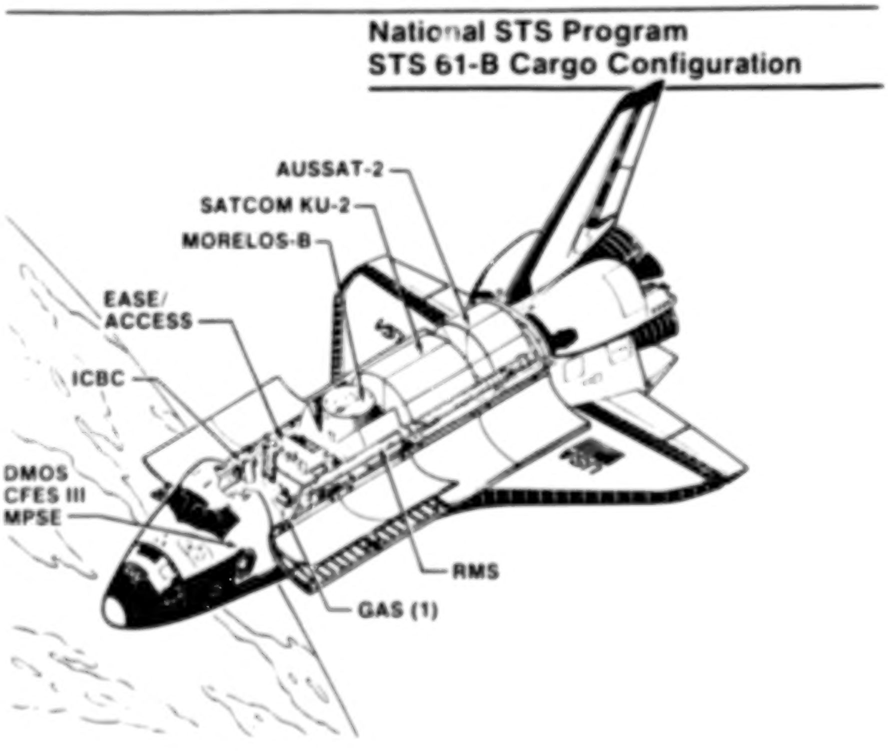


Figure 4

The objective of the meeting was to finalize the previously mentioned details so that all STS 61-B flight documentation would be ready for review at the STS 61-B Flight Operations Review (FOR).

On August 13, 1985, the STS 61-B FOR was conducted to verify the EASE/ACCESS payload technical requirements. The purpose of the FOR was to determine the status of the STS flight operations implementation and to ensure that the training documentation, the JSC Mission Control Center (MCC) configuration, and the STS 61-B operational documentation were ready to support the final phase of training of STS 61-B flight crew and MCC operations support personnel. The basic products used to conduct the FOR and the resulting final products baselined at the FOR are shown in Figure 5.

The STS Flight Readiness Review (FRR) was conducted on November 18, 1985, prior to the launch of the STS 61-B mission. The STS 61-B FRR was conducted to verify that all of the STS/cargo integration activities had been completed and to certify that all flight elements were ready to perform the mission. Before the FRR, the SPPO, the other STS 61-B payload customers, and the STS Centers determined and verified their respective readiness to launch. The FRR is conducted by NASA Headquarters and is supported by all of the NASA STS Centers. The STS 61-B cargo integration/safety assessment was presented at the FRR by personnel from the JSC NSTSO.

MISSION OPERATIONS PROCESS

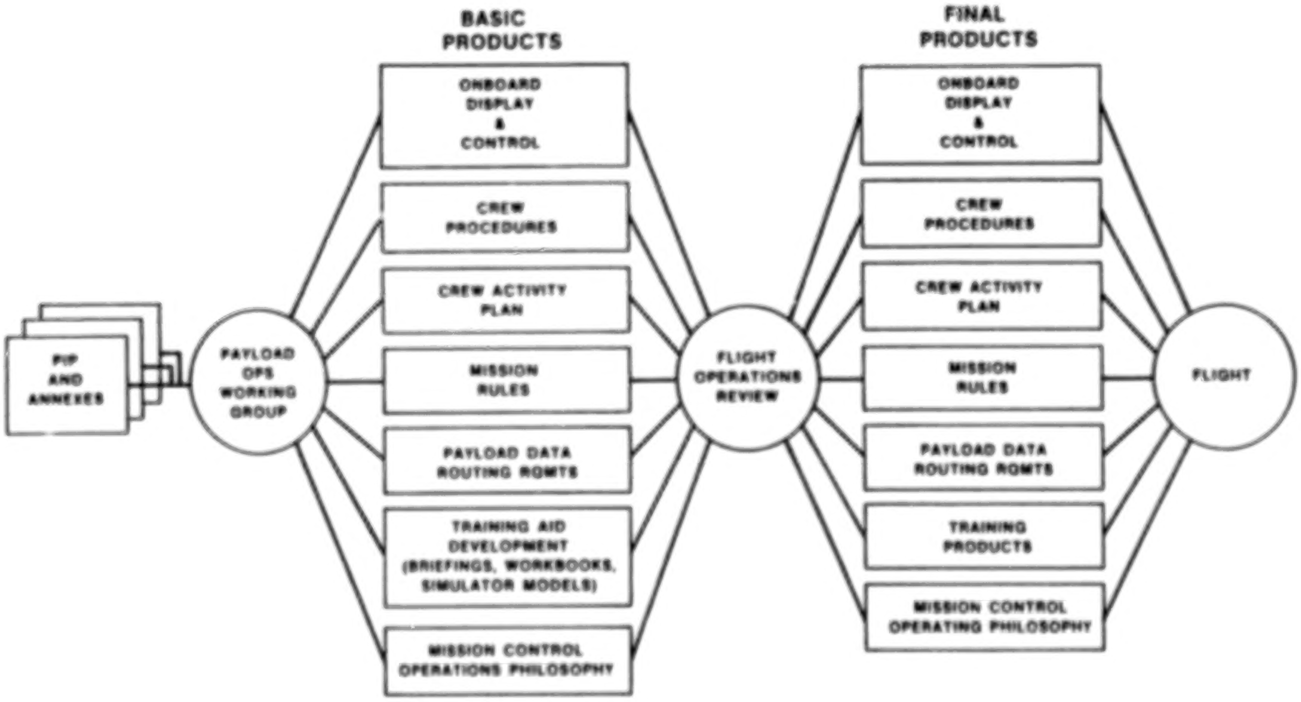
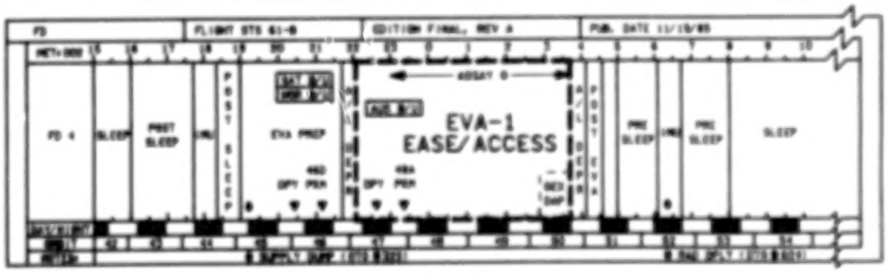

BASIC PRODUCTS
FINAL PRODUCTS
PIP AND ANNEXES
PAYLOAD OPS WORKING GROUP
ONBOARD DISPLAY & CONTROL
CREW PROCEDURES
CREW ACTIVITY PLAN
MISSION RULES
PAYLOAD DATA ROUTING RQMTS
TRAINING AID DEVELOPMENT (BRIEFINGS, WORKBOOKS, SIMULATOR MODELS)
MISSION CONTROL OPERATIONS PHILOSOPHY
FLIGHT OPERATIONS REVIEW
ONBOARD DISPLAY & CONTROL
CREW PROCEDURES
CREW ACTIVITY PLAN
MISSION RULES
PAYLOAD DATA ROUTING RQMTS
TRAINING PRODUCTS
MISSION CONTROL OPERATING PHILOSOPHY
FLIGHT

Figure 5

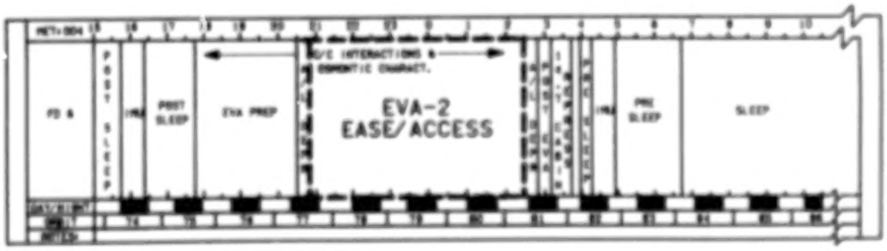
With the approval of the Flight Readiness Review Board to proceed with the planned mission, the launch of the STS 61-B crew and cargo occurred on November 26, 1985, from KSC in Florida and subsequently landed at Edwards Air Force Base, CA, on December 3, 1985. The Space Shuttle Orbiter Atlantis (OV-104) with five NASA astronauts and two payload specialists were launched to accomplish the STS 61-B mission objectives.

Two EVA's dedicated to EASE/ACCESS flight activities were a subset of the planned STS 61-B mission objectives. The first EVA, which occurred on mission flight day 4, had the two NASA EVA mission specialists exercise the EASE/ ACCESS payload hardware in the cargo bay with other NASA crewmembers collecting CCTV and photographic flight data on both the EASE and the ACCESS experiments. The second EVA, occurring on flight day 6, was used to evaluate the existing STS equipment and crew capabilities in carrying out the EASE/ACCESS Space Station Assembly Test DTO 0817. The portion of the STS 61-B mission Crew Activity Plan illustrating the two EVA days is shown in Figure 6. Specific details on both EVA's will be provided by both the experiment principal investigators and the STS 61-B flight crewmembers in other papers and discussions at this conference.

To support the EASE/ACCESS crew activities, in-flight payload support was provided by MSFC SPPO and EASE/ACCESS experiment management and technical personnel located in the JSC Customer Support Room (CSR) and in the MSFC Huntsville Operations Support Center (HOSC). Special communication tie-lines were provided to the EASE/ACCESS team during the mission between the JSC CSR and the MSFC HOSC to permit access to additional technical support at the MSFC HOSC. Besides the standard communication loops available in the CSR, a special communication loop was established to permit direct



FLIGHT DAY (FD) 4



FLIGHT DAY (FD) 6

Figure 6

discussions between the EASE/ACCESS management and technical team and the STS 61-B EVA officer. This EVA officer communication loop was of special importance during the mission to discuss EASE/ACCESS problems such as the failure of the EVA crewmembers to secure one of the two closure latches on an ACCESS equipment container and the difficulty the EVA crewmembers experienced when the EASE tetrahedral cell could not be refitted to the attachment node that secured the EASE cell to the payload carrier.

CONCLUSION

The EASE/ACCESS payload science objectives and the EASE/ACCESS Space Station Assembly Test Objective (DTO 0817) were fully achieved during both of the STS 61-B mission EVA's by the NASA crewmembers. The precision with which all of the participating crewmembers carried out their assigned duties was according to all of the prescribed mission documentation. In general, the mission went extremely well with the flight crew at times being well ahead of their planned mission timeline. The flight crewmembers proved once again that suited EVA crewmembers can do reasonably complex assembly tasks in space.

N88-10877

EASE/ACCESS GROUND PROCESSING AT KENNEDY SPACE CENTER

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Space Construction Conference
August 6-7, 1986
Langley Research Center
Hampton, Virginia

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ABSTRACT

The Kennedy Space Center (KSC) Payload Management and Operations Directorate is responsible for the processing of Space Shuttle payloads. KSC responsibilities begin prior to hardware arrival at the launch site and extend until the experiments are returned to the investigators after the flight.

KSC involvement with the integration and checkout of payloads begins with participation in experiment, Mission Peculiar Equipment (MPE), and integrated payload design reviews. This involvement also includes participation in assembly and testing of flight hardware at the appropriate design center, university, or private corporation. Once the hardware arrives at the launch site, KSC personnel install the experiments and MPE onto a carrier in the Operations and Checkout (O&C) building. Following integration, the payload is functionally tested and then installed into the orbiter. After the mission, the payload is removed from the orbiter, deintegrated in the O&C building, and the experiments are turned over to the mission manager.

One of the many payloads processed at KSC consisted of two space construction experiments: the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS). This paper addresses the details of EASE/ACCESS integration, testing, and deintegration and discusses how this mission can serve as a guide for future space construction payloads.

INTRODUCTION

With the advent of the Space Station era, large truss structures in space will become the framework for on-orbit operations. To develop optimal techniques for building truss assemblies in zero-gravity, construction experiments must be performed. Two space construction experiments, EASE and ACCESS, recently were flown aboard the Space Transportation System (STS). The Space Shuttle has carried many scientific experiments into orbit. The final integration and verification of all Shuttle payloads occurs at the Kennedy Space Center (KSC) in Florida.

The various elements that comprise a payload arrive at the launch site from their individual design centers and are assembled and verified at KSC. All assembly and testing of the components are performed by KSC personnel. Each experiment is installed onto a carrier, such as a Mission Peculiar Equipment Suppport Structure (MPESS) or a pallet, and then tested to verify proper function. The entire payload is then installed into the orbiter and final preparations for launch are completed. After the mission, the payload is returned to KSC for deintegration.

KSC ORGANIZATION

STS activities at KSC are separated into two general categories: Shuttle operations and payload operations. The KSC organizational chart is shown Figure 1. The Shuttle Operations Directorate is responsible for the processing, launching, and landing of the Shuttle. This includes refurbishing the orbiter after each flight and mating it to the external tank and solid rocket boosters. Lockheed Space Operations Company is the Shuttle processing contractor and performs the actual "hands-on" operations.

The KSC Payload Management and Operations Directorate, on the other hand, is responsible for all payload processing at the launch site, including payloads flown on expendable vehicles. Within this directorate, the STS Payload Operations Directorate handles the processing of both horizontal and vertical Shuttle payloads. Vertical payloads, such as the Space Telescope and all satellites, are installed onto a carrier in the vertical position. Horizontal payloads, such as Spacelabs and partial payloads, are integrated onto a carrier in the horizontal position. Horizontal payload processing is performed by the Spacelab and Experiments Division. Several other offices, such as the safety office and the quality assurance office, also provide support for payload integration.

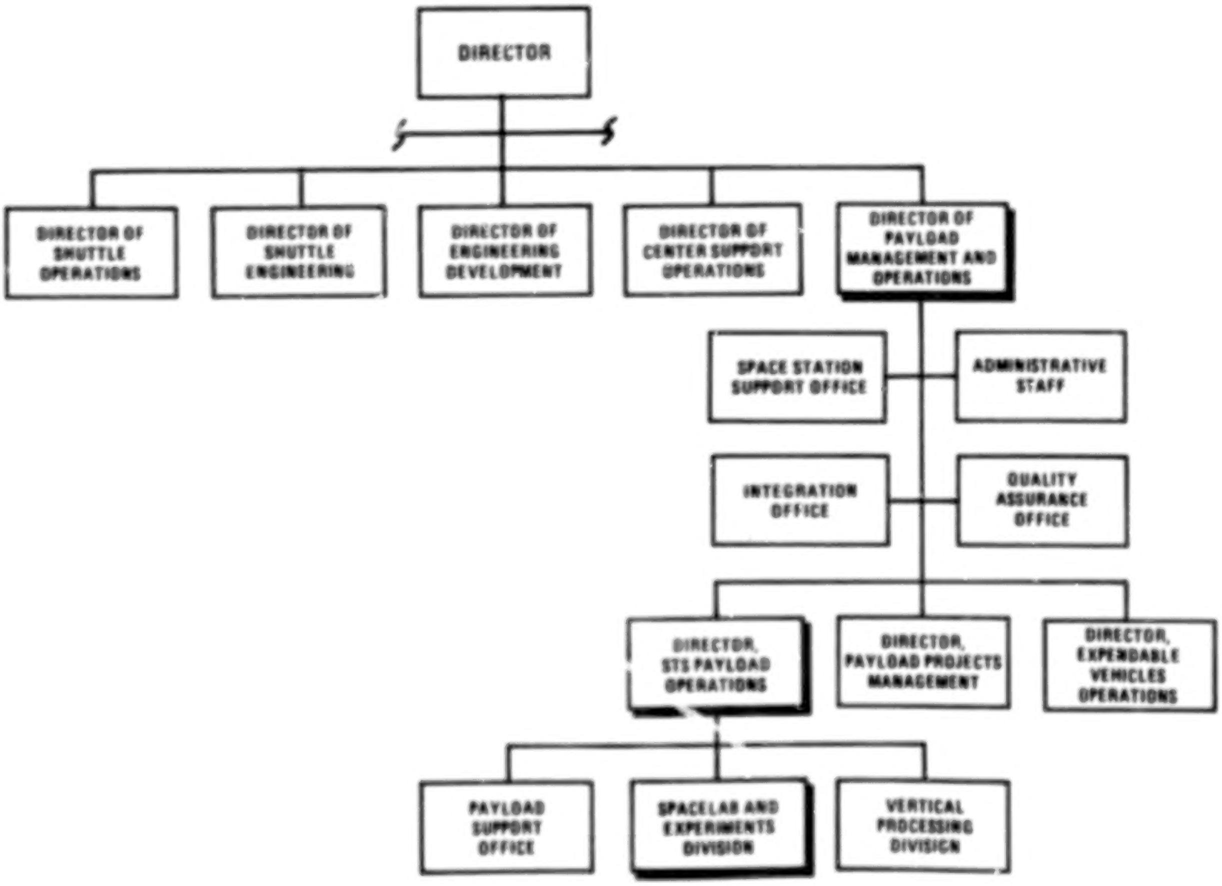
DIRECTOR
DIRECTOR OF SHUTTLE OPERATIONS
DIRECTOR OF SHUTTLE ENGINEERING
DIRECTOR OF ENGINEERING DEVELOPMENT
DIRECTOR OF CENTER SUPPORT OPERATIONS
DIRECTOR OF PAYLOAD MANAGEMENT AND OPERATIONS
SPACE STATION SUPPORT OFFICE
ADMINISTRATIVE STAFF
INTEGRATION OFFICE
QUALITY ASSURANCE OFFICE
DIRECTOR, STS PAYLOAD OPERATIONS
DIRECTOR, PAYLOAD PROJECTS MANAGEMENT
DIRECTOR, EXPENDABLE VEHICLES OPERATIONS
PAYLOAD SUPPORT OFFICE
SPACELAB AND EXPERIMENTS DIVISION
VERTICAL PROCESSING DIVISION

FIGURE 1 – NASA ORGANIZATIONAL CHART, JOHN F. KENNEDY SPACE CENTER

In the Spacelab and Experiments Division, NASA engineers perform hands-on work with flight hardware and ground support equipment. Figure 2 shows the breakdown of NASA and contractor roles in payload processing. NASA personnel are assisted by Boeing Aerospace Operations technicians. McDonnell Douglas Astronautics Corporation is the payload interface to the Shuttle organization and is also responsible for integrating Spacelab carriers.

Every horizontal experiment processed by the Spacelab and Experiments Division is assigned a NASA mechanical engineer and a NASA test conductor. These two engineers, along with the payload's launch site support manager,

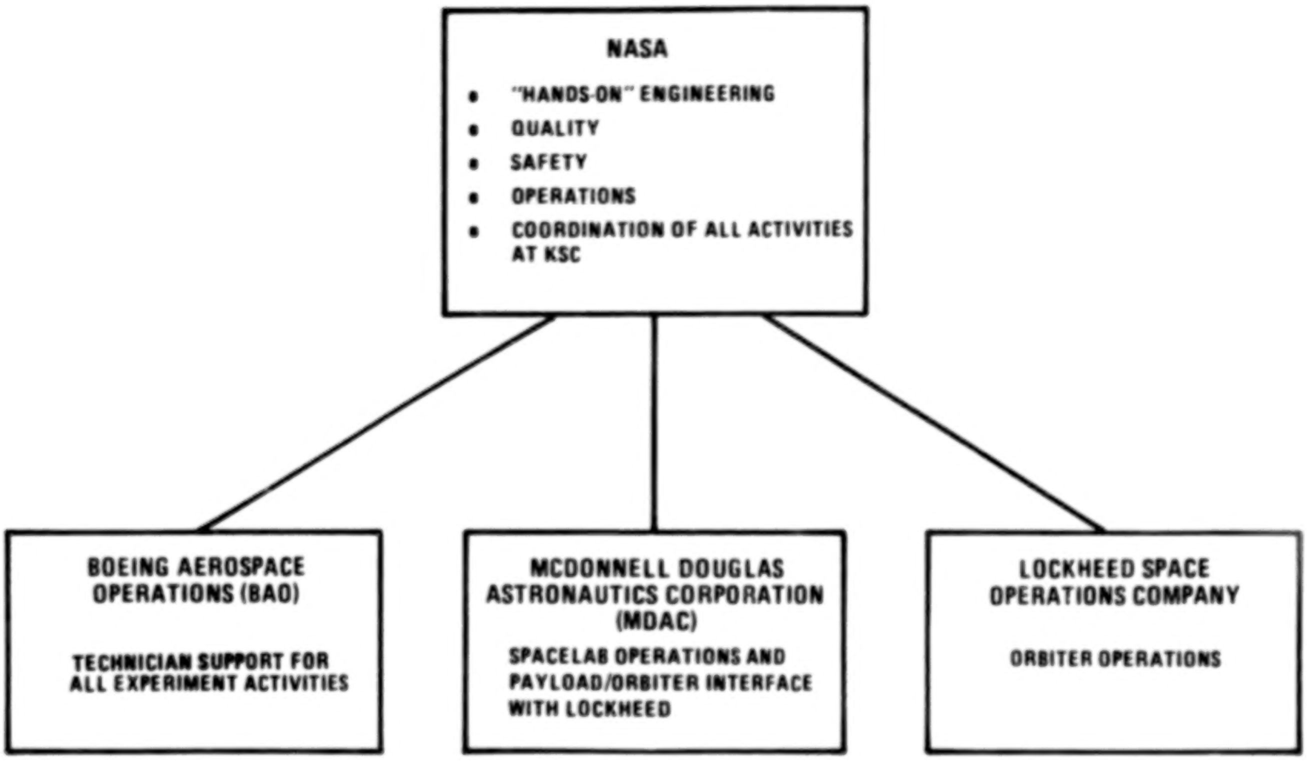
NASA
"HANDS-ON" ENGINEERING
QUALITY
SAFETY
OPERATIONS
COORDINATION OF ALL ACTIVITIES AT KSC
BOEING AEROSPACE OPERATIONS (BAO)
TECHNICIAN SUPPORT FOR ALL EXPERIMENT ACTIVITIES
MCDONNELL DOUGLAS ASTRONAUTICS CORPORATION (MDAC)
SPACELAB OPERATIONS AND PAYLOAD/ORBITER INTERFACE WITH LOCKHEED
LOCKHEED SPACE OPERATIONS COMPANY
ORBITER OPERATIONS

FIGURE 2 – NASA/CONTRACTOR PAYLOAD RESPONSIBILITIES AT KSC

serve as the primary contacts at KSC for the investigator as shown in Figure 3. The mechanical engineer is responsible for reviewing preliminary drawings of the experiment, participating in payload design reviews, installing the experiment onto the carrier, and removing the experiment after the flight. The test conductor is an engineer who is responsible for testing all experiment interfaces and for verifying that the experiment functions properly. The test conductor is also responsible for any additional tests that may be required, such as experiment calibration or periodic maintenance. The launch site support manager serves as the point of contact for the investigators before the experiment arrives at KSC.

Other personnel within the division are assigned additional tasks on a payload basis. For example, the electrical and mechanical branches each have an individual who coordinates the required effort from that office for each payload. In addition, an operations engineer is assigned to develop and track the payload schedule and to coordinate this schedule with those of other payloads also being processed at KSC simultaneously. To ensure that all top level payload requirements are met, a NASA payload manager is also assigned to each mission.

During the ground processing of a payload, KSC engineers work closely with the design center, the investigators, and orbiter personnel. For the EASE/ACCESS mission, the Marshall Space Flight Center was the mission management agency and was responsible for coordinating the integration of the two experiments onto the carrier. The EASE and ACCESS investigators were from the Massachussettes Institute of Technology and Langley Research Center,

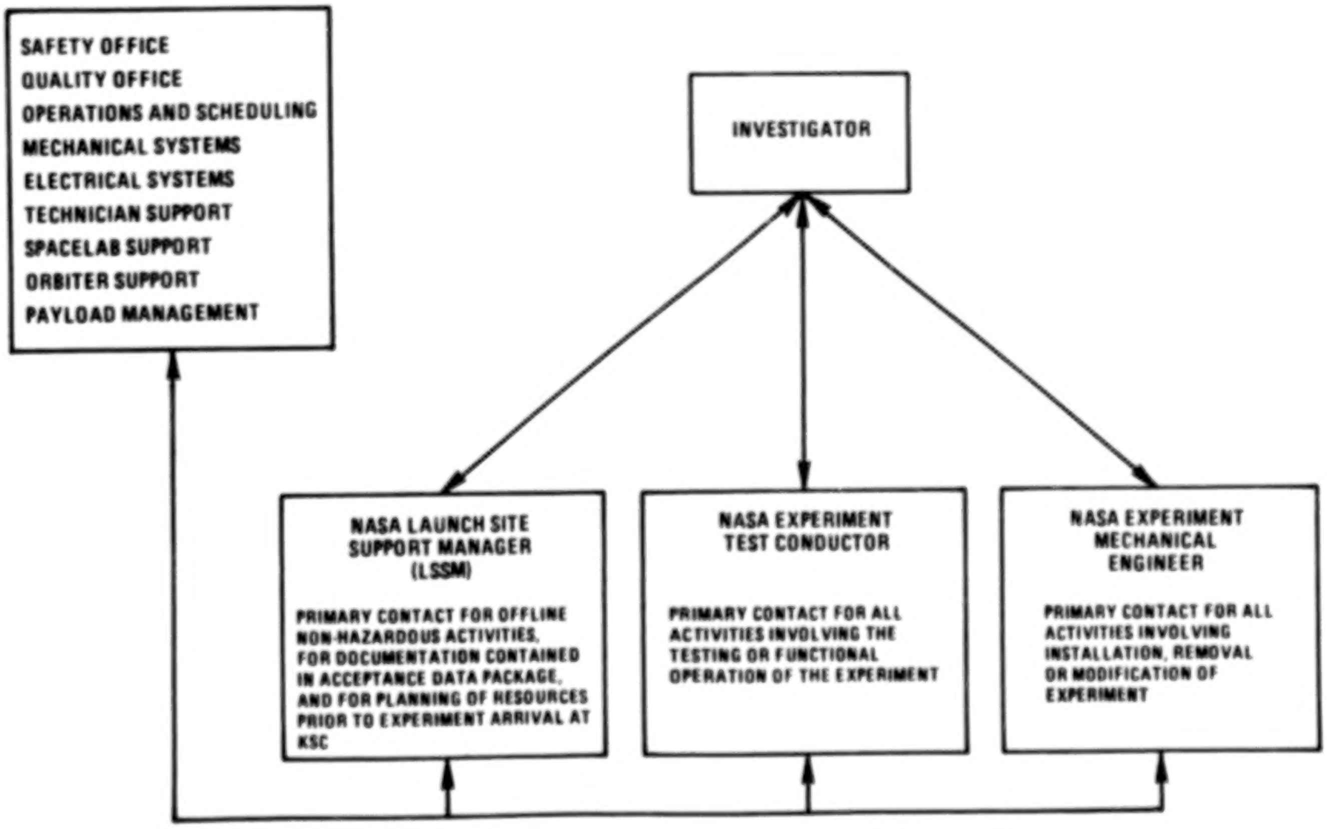
SAFETY OFFICE
QUALITY OFFICE
OPERATIONS AND SCHEDULING
MECHANICAL SYSTEMS
ELECTRICAL SYSTEMS
TECHNICIAN SUPPORT
SPACELAB SUPPORT
ORBITER SUPPORT
PAYLOAD MANAGEMENT
INVESTIGATOR
NASA LAUNCH SITE SUPPORT MANAGER (LSSM)
PRIMARY CONTACT FOR OFFLINE NON-HAZARDOUS ACTIVITIES, FOR DOCUMENTATION CONTAINED IN ACCEPTANCE DATA PACKAGE, AND FOR PLANNING OF RESOURCES PRIOR TO EXPERIMENT ARRIVAL AT KSC
NASA EXPERIMENT TEST CONDUCTOR
PRIMARY CONTACT FOR ALL ACTIVITIES INVOLVING THE TESTING OR FUNCTIONAL OPERATION OF THE EXPERIMENT
NASA EXPERIMENT MECHANICAL ENGINEER
PRIMARY CONTACT FOR ALL ACTIVITIES INVOLVING INSTALLATION, REMOVAL OR MODIFICATION OF EXPERIMENT

FIGURE 3 – INVESTIGATOR/KSC INTERFACES

respectively. As for all Space Shuttle missions, the Johnson Space Center was the interface for orbiter and crew operations.

ACTIVITIES PRIOR TO HARDWARE ARRIVAL

At the same time that an experiment is being finalized at its design center, the investigator begins to work with KSC personnel to ensure that all of the experiment requirements will be satisfied. One of the most important steps for the investigator is to state all planned experiment activities in the Ground Integration Requirements Document (GIRD). This document is printed by the payload mission manager and one GIRD exists for each payload; thus, the requirements for all experiments on the same flight are included in the same GIRD. All payload activities and support services at KSC must be requested in the GIRD. This includes installation of the experiment onto the carrier, testing of the experiment, any required calibration, and any necessary maintenance. If any activity is not listed in the GIRD, it will not be performed at KSC, unless it results from an unforeseen problem. Therefore, the investigators must be certain that they have listed every planned event in the GIRD.

In addition to listing the payload requirements, the GIRD contains a deliverable items list identifying all payload equipment to be delivered to KSC. This information enables KSC to plan for equipment storage space on center and to keep track of all items stored at KSC. The GIRD also contains a section on contingency landing requirements. The list of deliverable items and the contingency landing requirements are both used by KSC to develop the Off-Site Plan, Annex 21 to the NASA/Johnson Space Center Payload Integration Plan (PIP). The Off-Site Plan includes all payload support equipment that needs to be shipped to a contingency landing site if the orbiter does not land at the primary landing site.

KSC's formal response to the GIRD is the Launch Site Support Plan (LSSP), Annex 8 to the PIP. The LSSP addresses each GIRD requirement with a KSC response and commitment. KSC may not be able to fulfill some requirements based on existing capabilities. If a requirement is agreed to by KSC, a specific procedure or other commitment source will be identified in the LSSP. By working together with the investigators and the mission management team on finalizing the GIRD, KSC personnel are usually able to respond affirmatively to every requirement in the LSSP. This was the case with EASE/ACCESS. If KSC is unable to meet a specific requirement, this will be thoroughly discussed with the investigator and the mission manager before the experiment arrives at KSC.

In addition to the GIRD, another document exists which lists requirements involving orbiter support. This document is called the Operations and Maintenance Requirements Specifications Document. For space construction payloads, such as EASE/ACCESS, the only requirement involving orbiter support would probably be a bonding check of the carrier to the orbiter.

Prior to flight hardware arrival, KSC personnel participate in ground operations reviews and in integrated payload design reviews. Approximately a year before the EASE/ACCESS launch, KSC participated in the Integrated Payload Final Design and Operations Review at Marshall. KSC reviewed the data package, which included the payload integration drawings and the payload GIRD. Areas of interest were accuracy and completeness of hardware installation details and requirements. For every incomplete or questionable item, KSC submitted to Marshall a discrepancy notice which identified the problem. All notices were resolved by the mission management team and appropriate action resulted.

Payload planning meetings such as payload ground operations working group meetings and technical exchange meetings are held at KSC for most payloads. These meetings enable the experimenters to become familiar with KSC operations and allow KSC to learn more about the payload. Schedules, procedures, and other concerns are discussed at these meetings.

Another type of meeting scheduled at KSC consists of a series of ground safety reviews. These reviews are sponsored by the KSC safety office and attended by the mission manager. If a particular experiment has many hazardous operations or uses equipment that can be hazardous, then the mission manager can request that the investigators also attend. The purpose of these meetings is to identify and analyze all hazardous operations that will be performed at KSC during payload ground processing. Specialized handling instructions and precautions are agreed upon by all attendees. This information is then forwarded to the NASA engineer who will be performing the operation and will be responsible for ensuring the safety of the task.

In addition to reviewing the GIRD, addressing any applicable discrepancy notices, and participating in KSC-sponsored payload meetings, an investigator also interacts with KSC/NASA personnel by providing written procedures for all experiment activities specified in the GIRD. Also, the assigned NASA engineers usually travel to the experiment design center to learn first-hand how the equipment functions and how it should be integrated.

For the EASE/ACCESS payload, KSC/NASA engineers participated in the integration of mock-up EASE and ACCESS experiments and Mission Peculiar Equipment (MPE) onto a non-flight MPESS at Marshall. NASA personnel also participated in the integration and testing of the flight ACCESS experiment at Langley Research Center. These activities enabled KSC engineers to obtain detailed information from the investigators about their experiments. This participation also enabled KSC to estimate more accurately the integration time and the resources that would be required at the launch site. Using this information, NASA generated an EASE/ACCESS processing schedule for the entire payload flow at KSC.

Schedules are used at KSC as planning tools and as a method for implementing procedures and utilizing resources. The payload master schedule shows the payload flow at KSC from arrival on-dock (O/D) through deintegration. The payload integration schedule shows major milestones and a detailed breakdown of all payload work performed. This schedule is formulated prior to hardware arrival and is updated throughout the processing flow to reflect the as-run activities and any necessary changes for remaining work. Figures 4 and 5 show the as-run EASE/ACCESS master schedule and integration schedule, respectively.

Based on integration drawings, GIRD requirements, experience with hardware integration and testing at the design center, and experimenter inputs, the KSC/NASA engineers develop procedures for all planned activities. These documents are called Test and Assembly Procedures (TAP's). The purpose of an assembly procedure is to implement pre-planned payload activities. These procedures are written well in advance of the actual activity. The first draft of an assembly procedure is written several months prior to the use date. After being reviewed by the mission manager, the experimenters, KSC quality engineering, and the KSC safety office, the procedure is finalized and released for use. Up to three drafts of a document may be published before the final version is released. Several test and assembly procedures were written specifically for the EASE/ACCESS payload. These procedures included EASE installation, ACCESS installation, MPE installation, and ACCESS functional testing.

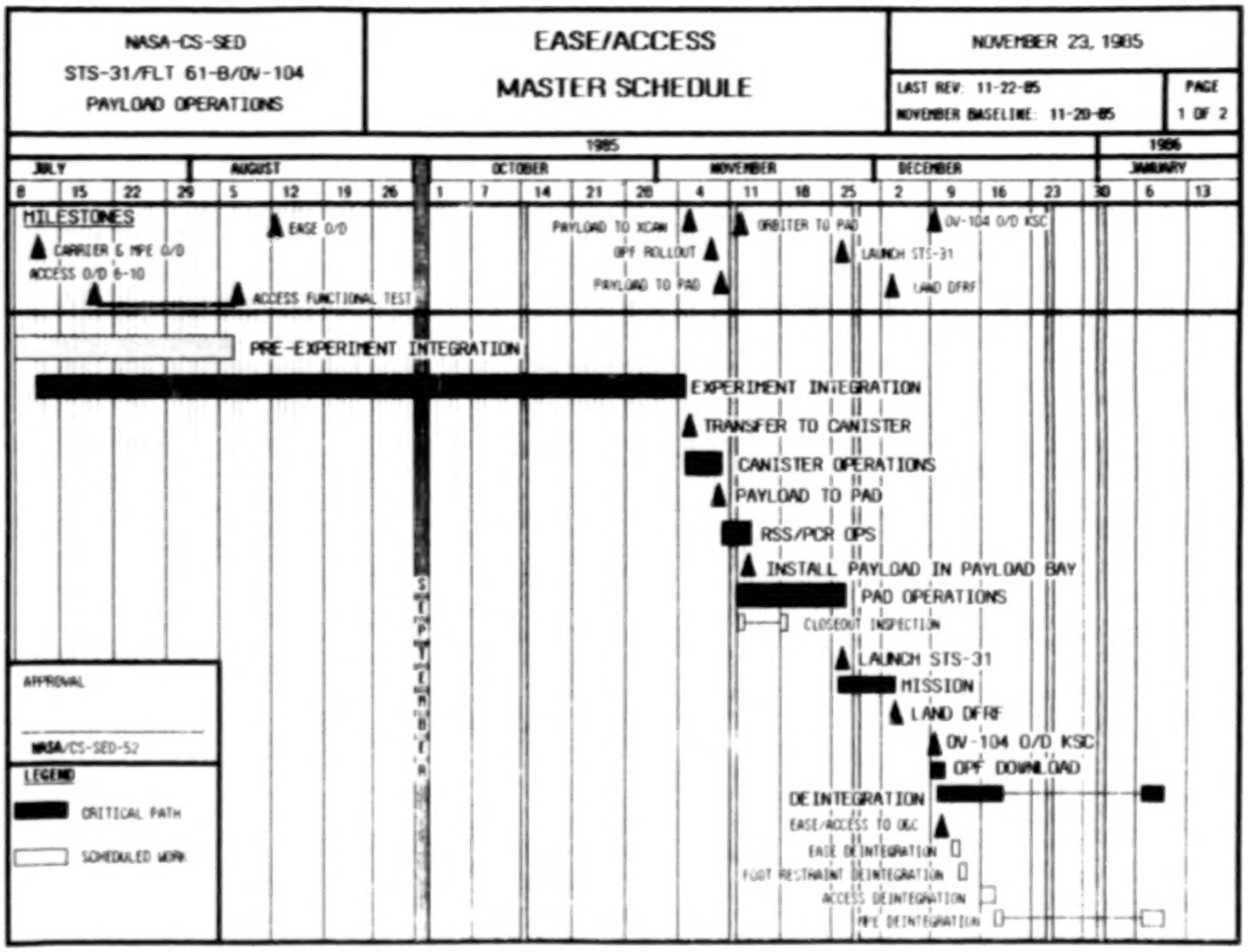

FIGURE 4 – EASE/ACCESS MASTER SCHEDULE

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A number of generic test and assembly procedures exist which can be performed on more than one payload. Standard procedures used for EASE/ACCESS processing included weight and balance determination, payload clearance checks, and MPESS/pallet payload closeout inspection. These same procedures can be used for processing future space construction experiments.

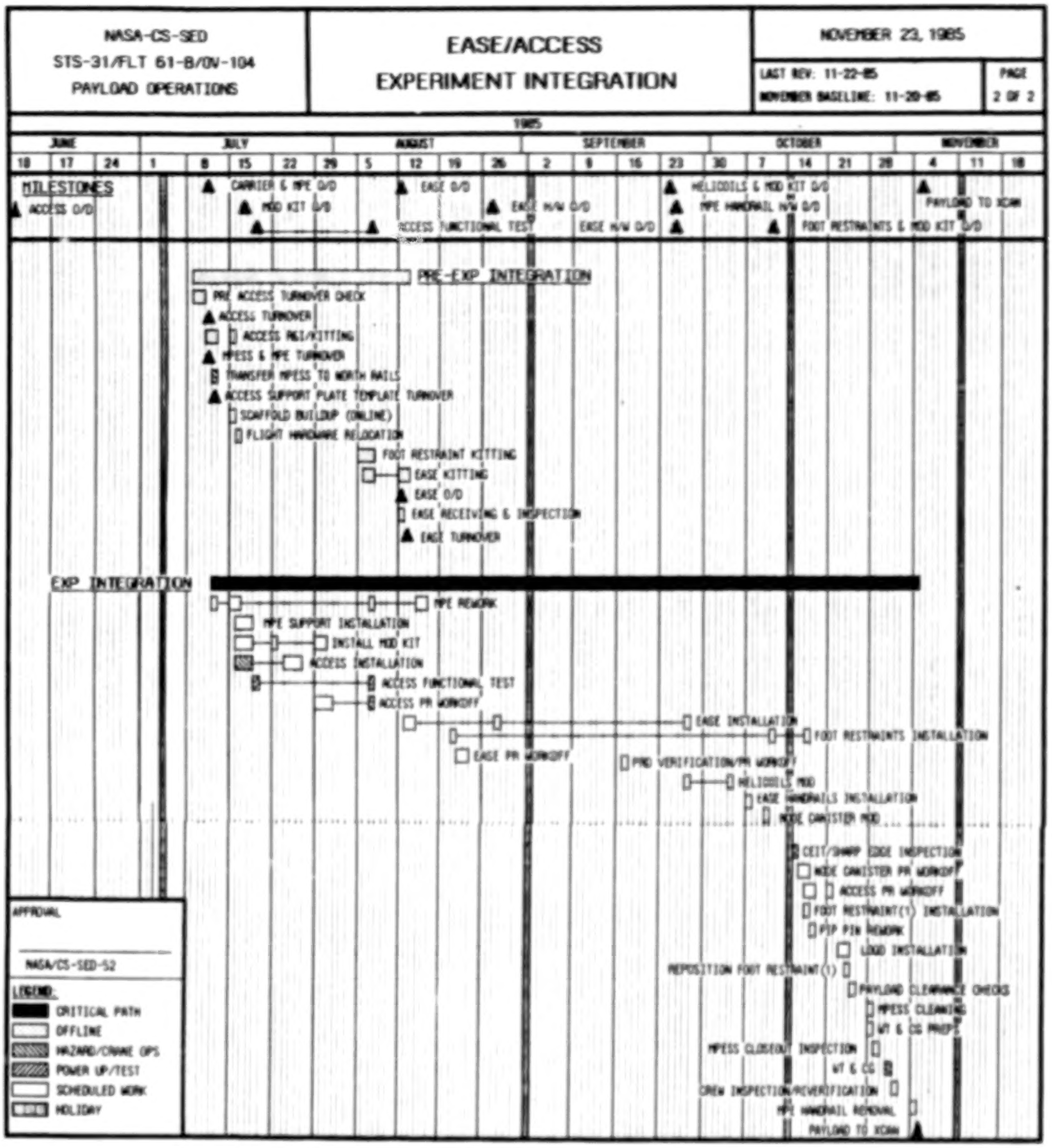

FIGURE 5 – EASE/ACCESS INTEGRATION SCHEDULE

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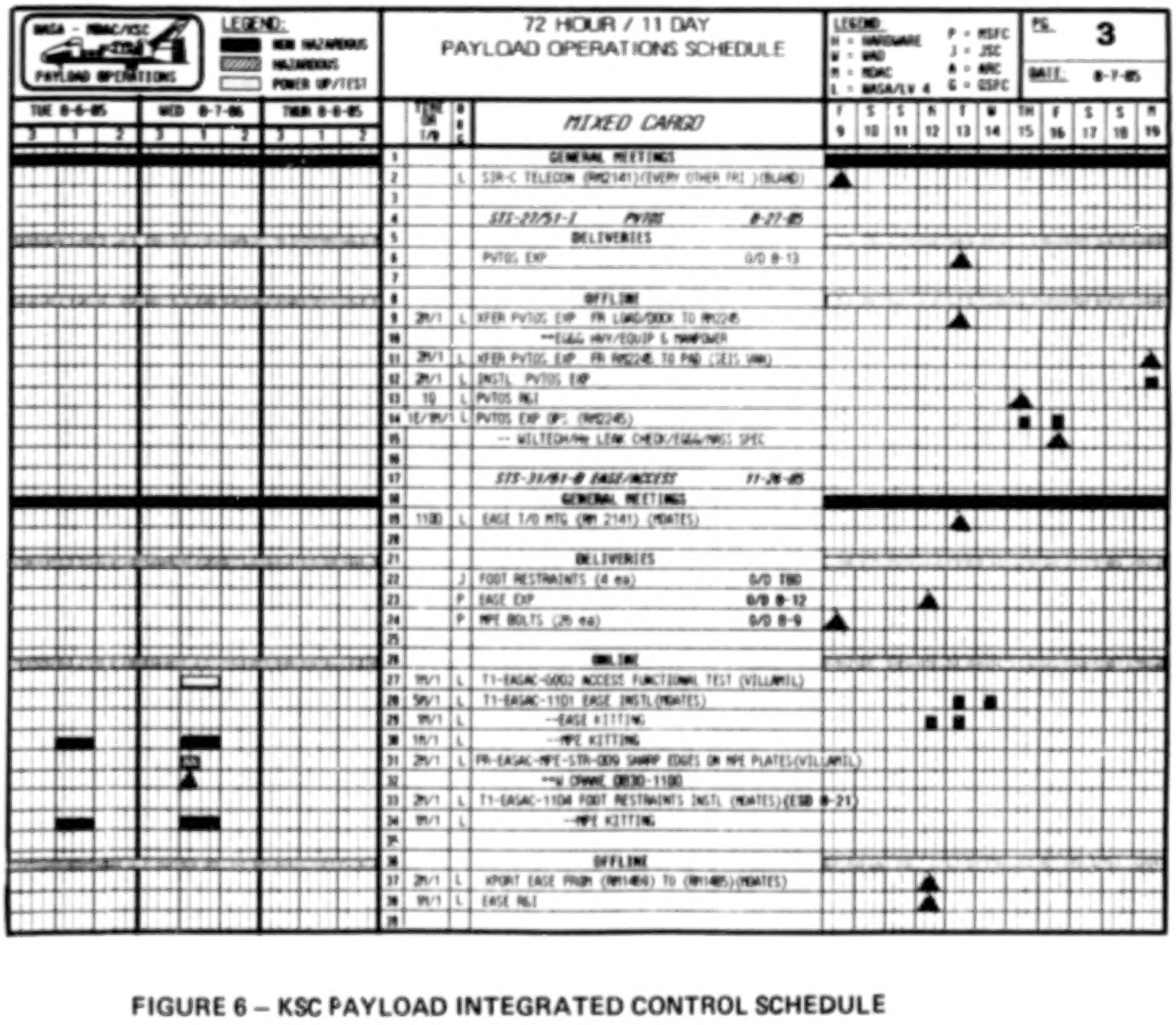
OFFLINE PAYLOAD PROCESSING

Once the experiments and the mission peculiar equipment begin to arrive at KSC, all activities appear in the KSC Payload Integrated Control Schedule. This is a detailed 72 hour/11 day schedule and is published daily. Hardware deliveries, experiment installations, functional tests, and facility requirements are all listed in the schedule. The time required to perform a scheduled activity is indicated in hours for the first 72 hour period and in shifts for the following 11 day period. The technician and Quality Assurance support required for an activity is also indicated, as well as any other necessary support. Figure 6 is an example of a page from the schedule.



NASA - MDAC/KSC
PAYLOAD OPERATIONS

LEGEND:
■ NON HAZARDOUS
▨ HAZARDOUS
☐ POWER UP/TEST

72 HOUR / 11 DAY
PAYLOAD OPERATIONS SCHEDULE

LEGEND:
H = HARDWARE
W = WAD
M = MDAC
L = NASA/LV 4
P = MSFC
J = JSC
A = ARC
G = GSFC

PG. 3
DATE: 8-7-85

TUE 8-6-85 | WED 8-7-85 | THUR 8-8-85

F 9 | S 10 | S 11 | M 12 | T 13 | W 14 | TH 15 | F 16 | S 17 | S 18 | M 19

	TIME OR T/O		MIXED CARGO	
1			GENERAL MEETINGS	
2		L	SIR-C TELECON (RM2141)(EVERY OTHER FRI)(BLAND)	
3				
4			STS-27/51-I PVTOS	8-27-85
5			DELIVERIES	
6			PVTOS EXP	O/D 8-13
7				
8			OFFLINE	
9	2H/1	L	XFER PVTOS EXP FR LOAD/DOCK TO RM2245	
10			--EG&G HVY/EQUIP & MANPOWER	
11	2H/1	L	XFER PVTOS EXP FR RM2245 TO PAD (SEIS VAN)	
12	2H/1	L	INSTL PVTOS EXP	
13	1Q	L	PVTOS R&I	
14	1E/1H/1	L	PVTOS EXP OPS (RM2245)	
15			-- WILTECH/He LEAK CHECK/EG&G/NASS SPEC	
16				
17			STS-31/61-B EASE/ACCESS	11-26-85
18			GENERAL MEETINGS	
19	1100	L	EASE T/O MTG (RM 2141) (MOATES)	
20				
21			DELIVERIES	
22		J	FOOT RESTRAINTS (4 ea)	O/D TBD
23		P	EASE EXP	O/D 8-12
24		P	MPE BOLTS (25 ea)	O/D 8-9
25				
26			ONLINE	
27	1H/1	L	T1-EASAC-0002 ACCESS FUNCTIONAL TEST (VILLAMIL)	
28	5H/1	L	T1-EASAC-1101 EASE INSTL(MOATES)	
29	1H/1	L	--EASE KITTING	
30	1H/1	L	--MPE KITTING	
31	2H/1	L	PR-EASAC-MPE-STR-0009 SHARP EDGES ON MPE PLATES(VILLAMIL)	
32			--W CRANE 0830-1100	
33	2H/1	L	T1-EASAC-1104 FOOT RESTRAINTS INSTL (MOATES)(ESD 8-21)	
34	1H/1	L	--MPE KITTING	
35				
36			OFFLINE	
37	2H/1	L	XPORT EASE FROM (RM1486) TO (RM1485)(MOATES)	
38	1H/1	L	EASE R&I	
39				

FIGURE 6 – KSC PAYLOAD INTEGRATED CONTROL SCHEDULE

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All horizontal payloads follow the processing flow outlined in Figure 7. Payload hardware arrives at the O&C building located in the industrial area of KSC, shown in Figure 8. After the hardware is offloaded from the plane or truck, a quality inspector performs a receiving and inspection. This process includes a visual verification that no shipping damage has occurred and a check that all items and applicable documentation have been received. Afterwards, the experimenter is free to perform any offline activities that are necessary, if such a request had been previously stated in the GIRD. Offline labs are available for experimenters on an individual basis, and KSC can provide limited resources, such as darkrooms, laminar flow benches, centrifuges, sinks, and certain common fluids and gases. In all cases, the request for an offline lab or for supporting equipment must be included in the GIRD, and KSC's response as to whether or not the service can be provided is listed in the LSSP.

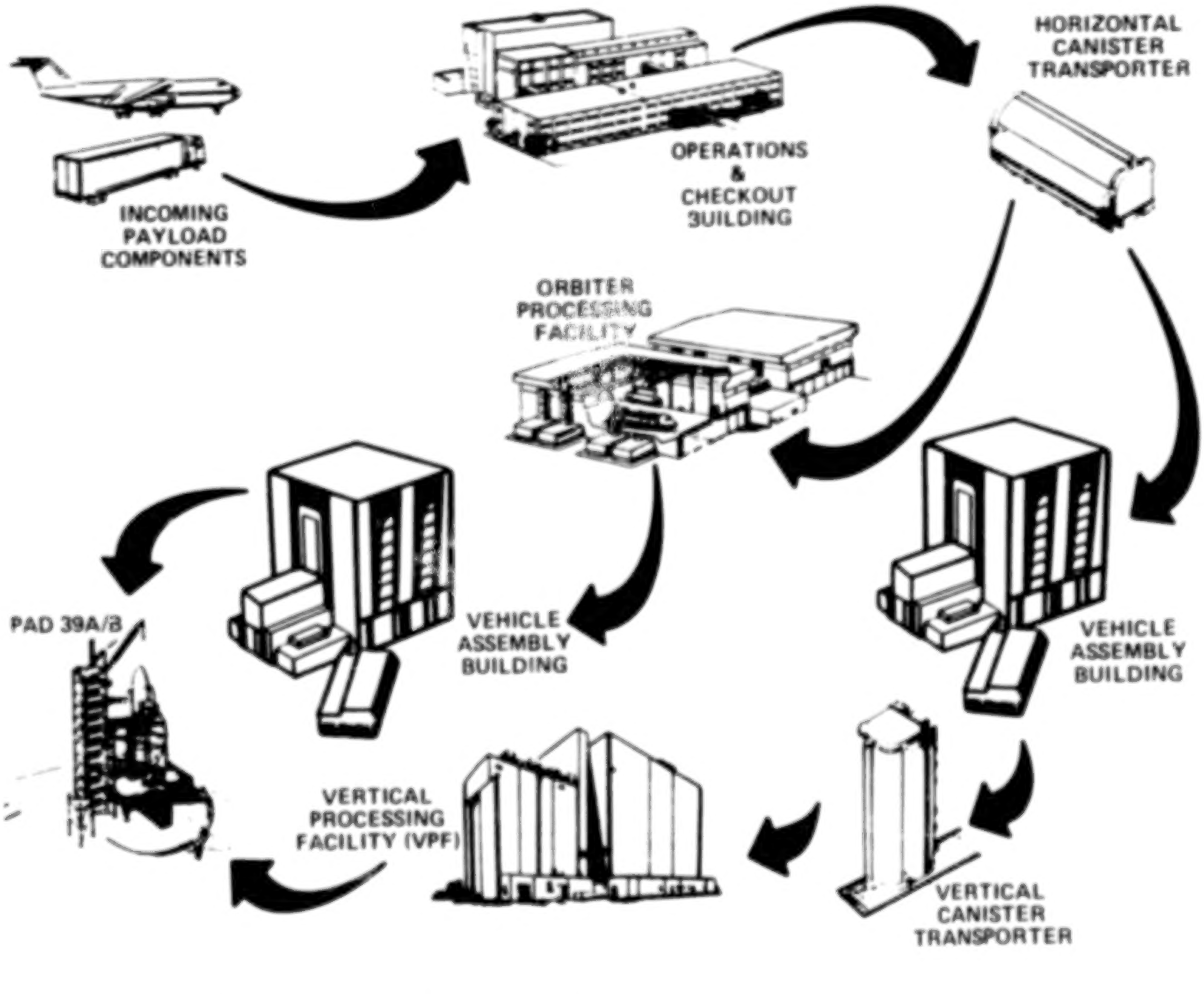
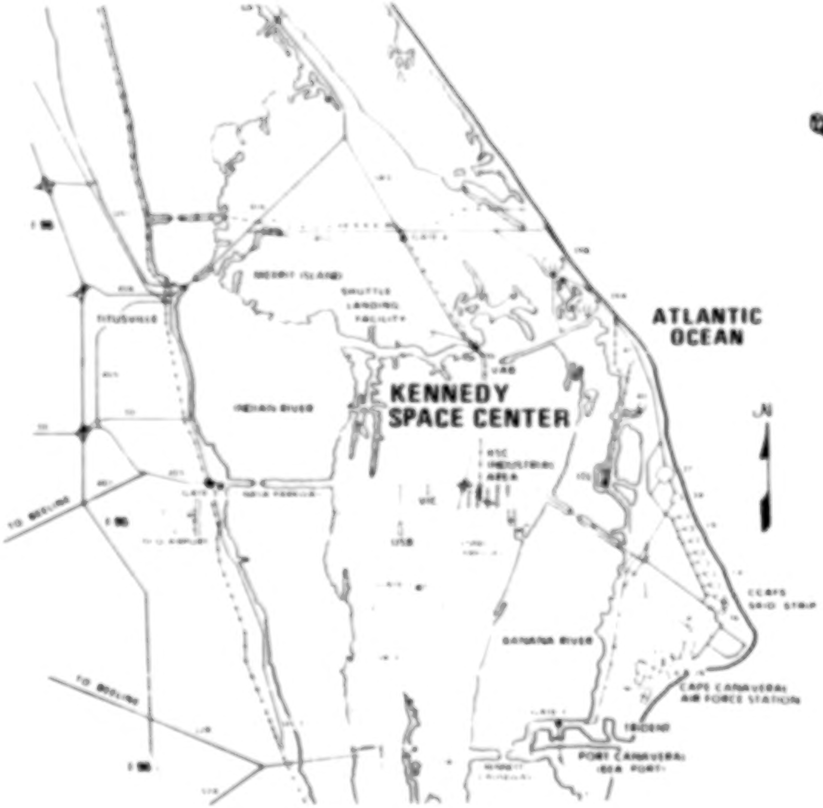
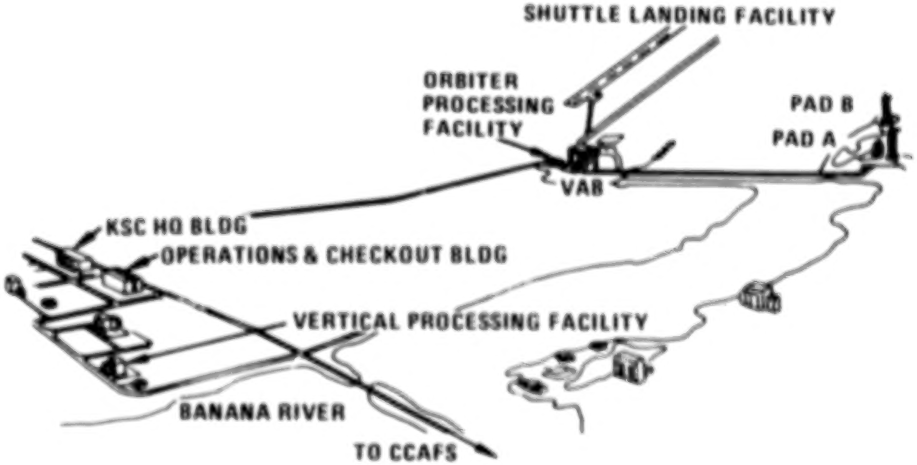

INCOMING PAYLOAD COMPONENTS
OPERATIONS & CHECKOUT BUILDING
HORIZONTAL CANISTER TRANSPORTER
ORBITER PROCESSING FACILITY
VEHICLE ASSEMBLY BUILDING
VEHICLE ASSEMBLY BUILDING
PAD 39A/B
VERTICAL PROCESSING FACILITY (VPF)
VERTICAL CANISTER TRANSPORTER

FIGURE 7 – HORIZONTAL PAYLOAD PROCESSING FLOW



KSC AND SURROUNDING AREA


SHUTTLE LANDING FACILITY
ORBITER PROCESSING FACILITY
PAD B
PAD A
VAB
KSC HQ BLDG
OPERATIONS & CHECKOUT BLDG
VERTICAL PROCESSING FACILITY
BANANA RIVER
TO CCAFS

FACILITIES USED FOR HORIZONTAL PAYLOAD PROCESSING

FIGURE 8 – KSC AREA MAP

Many experiments arrive at KSC ready for installation and require no offline activities. This was the case with the EASE experiment. The ACCESS experiment, on the other hand, went first to an offline lab where the experimenter checked out the operation of the struts and the nodes.

The offline labs can also be used for other activities, such as loading film or pressurizing an experiment. Investigators perform all work under their own paperwork system if there are no hazards involved. If any of the offline activities are hazardous, such as a crane lift or an operation involving high pressure, then a NASA engineer will be responsible for writing a Test Preparation Sheet (TPS) to perform the operation. This procedure will be reviewed by the safety office and the activity will be performed under the NASA task leader's direction.

In addition to being used for offline hazardous activities, test preparation sheets are also used for unplanned online activities and for events that do not require any significant support beyond a NASA engineer, Boeing technicians and NASA quality assurance. The major differences between a test preparation sheet and an assembly procedure are that the first is less formal and that no preliminary drafts are published. Therefore, a test preparation sheet is usually written just prior to use and needs to be reviewed only by the appropriate KSC personnel. Most hardware changeouts, modifications, and deintegrations are performed using a test preparation sheet.

After offline activities, the next step in the processing flow is hardware turnover to KSC. A quality engineer reviews the acceptance data package which accompanies every item of flight hardware that arrives at KSC. The data package contains updated drawings for the flight hardware, a list of non-flight items that are currently installed on the flight hardware (such as ground lifting rings), any required certifications (such as proofload data), any existing waivers or deviations, a list of open work that still needs to be completed, and any problem reports documenting nonconformance items. Quality engineering verifies that all of the required material is present. Quality personnel also write a KSC problem report for every nonconformance item and for any open work that was not previously scheduled to be performed at KSC. In addition, the quality engineer logs all non-flight hardware in the payload's non-flight equipment/red streamer log, and a red "Remove Before Flight" streamer is attached to each of these items. At this point, the payload has been officially turned over to KSC and is considered to be online. All further experiment operations are performed by NASA/Boeing personnel and all activities are documented in the KSC paperwork system.

The paperwork system used at KSC ensures that all payload activity is coordinated and that results are properly recorded. The documents show fulfillment of GIRD requirements and indicate any configuration changes performed at KSC. From these documents, all payload work performed at KSC can be reconstructed and verified. Regardless of the type of document used for a payload activity, each step is stamped by a technician or signed by an engineer and stamped by a quality inspector as appropriate. This method of tracking the work performed enables any reader to identify what steps were successfully completed and which personnel were involved. If at any point in the processing flow a problem or potential problem arises, a problem report is generated by the quality inspector. This report tracks the nonconformance item and is used to return the hardware to flight configuration. When either a procedure is completed or a problem documented on a problem report is solved, then the appropriate procedure or report is officially closed. This means that all necessary operations have been accomplished and that no open work remains. If the experiment cannot be returned to the originally planned flight configuration because of a problem, then the condition must be approved by the appropriate personnel before the problem report can be closed.

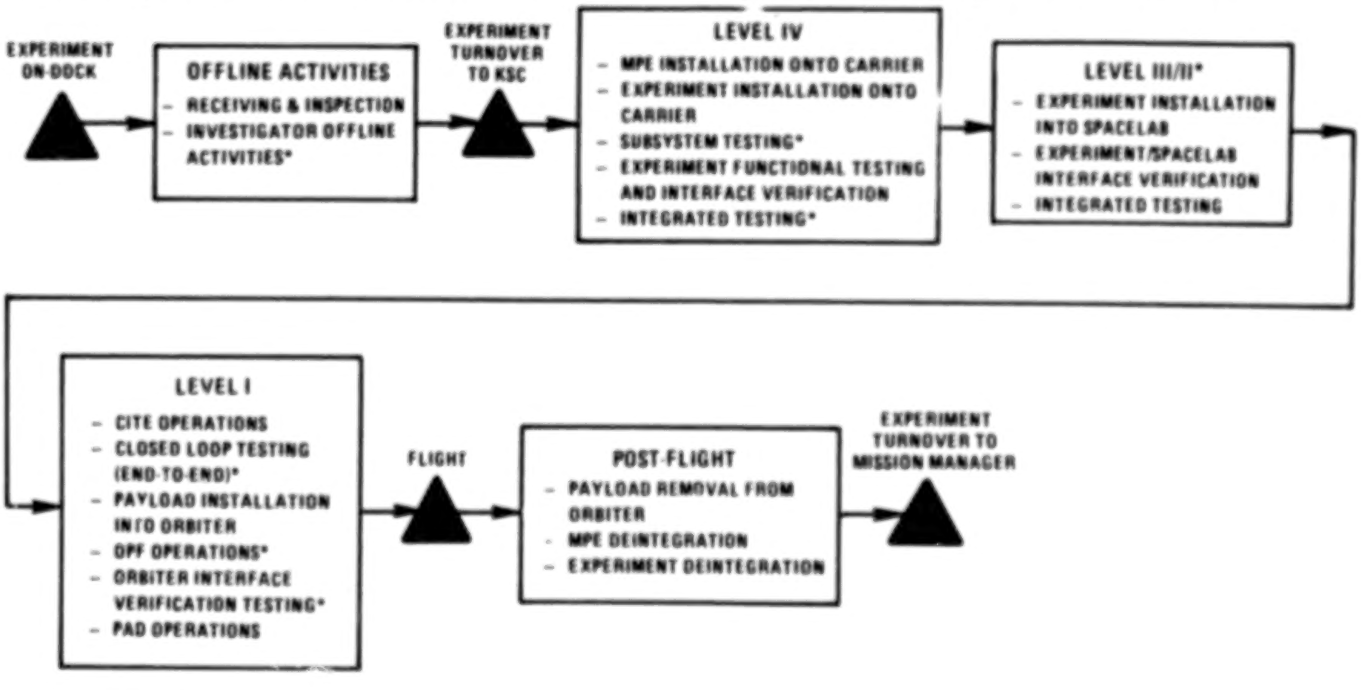
Throughout all payload processing, KSC personnel evaluate experiment operations to determine and predict possible problems that may occur. Many times, a specific item of experiment hardware may not appear to be problematic to the investigator but may, in fact, interfere with the operations of another nearby experiment. KSC personnel keep in mind the operation of the entire payload when working with individual experiments. This helps to identify potential problems before they occur.

During the review of the EASE acceptance data package, material usage agreements and deviations that had not yet been fully approved were found. A problem report was written to track these nonconformance items. The problem report could not be closed until several months later when proper documentation was received from Marshall. During receiving and inspection of EASE, minor paint scratches on the cradle assemblies were discovered. The problem was resolved the following week by performing touch-up painting of the hardware.

No problems were encountered during the ACCESS experiment turnover. Several red "Remove Before Flight" streamers had to be attached to ACCESS, however, since non-flight lifting hardware arrived installed on the experiment.

ONLINE PAYLOAD PROCESSING

Shuttle payloads go through a maximum of three levels of processing: Level IV, a combined Level III/II, and Level I. Reference Figure 9. Level IV


EXPERIMENT ON-DOCK
OFFLINE ACTIVITIES
– RECEIVING & INSPECTION
– INVESTIGATOR OFFLINE ACTIVITIES*
EXPERIMENT TURNOVER TO KSC
LEVEL IV
– MPE INSTALLATION ONTO CARRIER
– EXPERIMENT INSTALLATION ONTO CARRIER
– SUBSYSTEM TESTING*
– EXPERIMENT FUNCTIONAL TESTING AND INTERFACE VERIFICATION
– INTEGRATED TESTING*
LEVEL III/II*
– EXPERIMENT INSTALLATION INTO SPACELAB
– EXPERIMENT/SPACELAB INTERFACE VERIFICATION
– INTEGRATED TESTING
LEVEL I
– CITE OPERATIONS
– CLOSED LOOP TESTING (END-TO-END)*
– PAYLOAD INSTALLATION INTO ORBITER
– OPF OPERATIONS*
– ORBITER INTERFACE VERIFICATION TESTING*
– PAD OPERATIONS
FLIGHT
POST-FLIGHT
– PAYLOAD REMOVAL FROM ORBITER
– MPE DEINTEGRATION
– EXPERIMENT DEINTEGRATION
EXPERIMENT TURNOVER TO MISSION MANAGER

*MAY NOT BE REQUIRED FOR EVERY PAYLOAD

FIGURE 9 – EXPERIMENT INTEGRATION LEVELS FOR HORIZONTAL PAYLOADS

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includes the installation of the experiment onto the carrier, the functional testing of the experiment, and the integrated testing of all experiments on the same carrier. Level III/II verifies experiment to carrier interfaces and only involves Spacelab missions. EASE/ACCESS bypassed this level, as would most future space construction experiments. Level I includes all simulated and actual orbiter testing and all payload/orbiter operations.

The majority of online payload operations occurs in the O&C low bay, a class 100,000 clean area (airborne particles). Clean room garments must be worn in the proximity of flight hardware. The low bay is a secure area, and personnel entering the area must be badged appropriately. Two 27.5 ton capacity cranes are available for use during payload processing.

Located at one end of the O&C low bay are the Level IV test stands, followed by the Level III/II test stands, and finally the CITE stand (Cargo Integration Test Equipment). The low bay is shown in Figure 10, with the Level IV stands in the foreground. CITE simulates the orbiter and allows

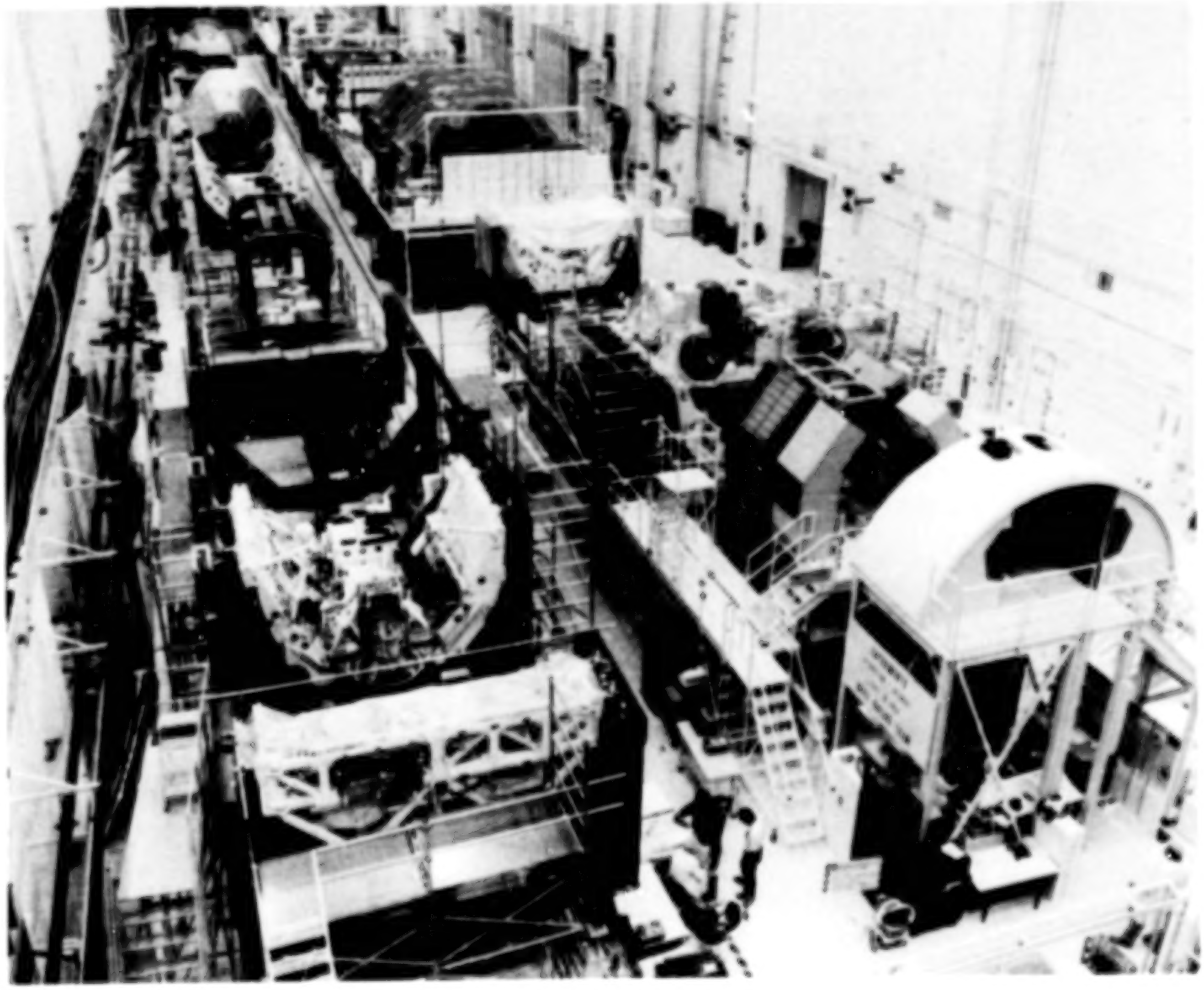


FIGURE 10 – OPERATIONS AND CHECKOUT BUILDING LOW BAY

payload-to-orbiter electrical interfaces to be verified. CITE marks the beginning of Level I. Level I continues when the payload is installed in the payload canister and taken to either the Orbiter Processing Facility or the pad, at which point the payload is installed into the Space Shuttle orbiter. All further payload operations until launch are also included as part of Level I processing.

MISSION PECULIAR EQUIPMENT INSTALLATION

Level IV integration begins with MPE installation onto the carrier. The carrier can be an MPESS (Mission Peculiar Equipment Support Structure), a Spacelab pallet, or other such structure. These carriers are flown inside the payload bay of the orbiter, as shown in Figure 11. The EASE/ACCESS payload used an MPESS. Normally, KSC's first task would have been to install the MPE

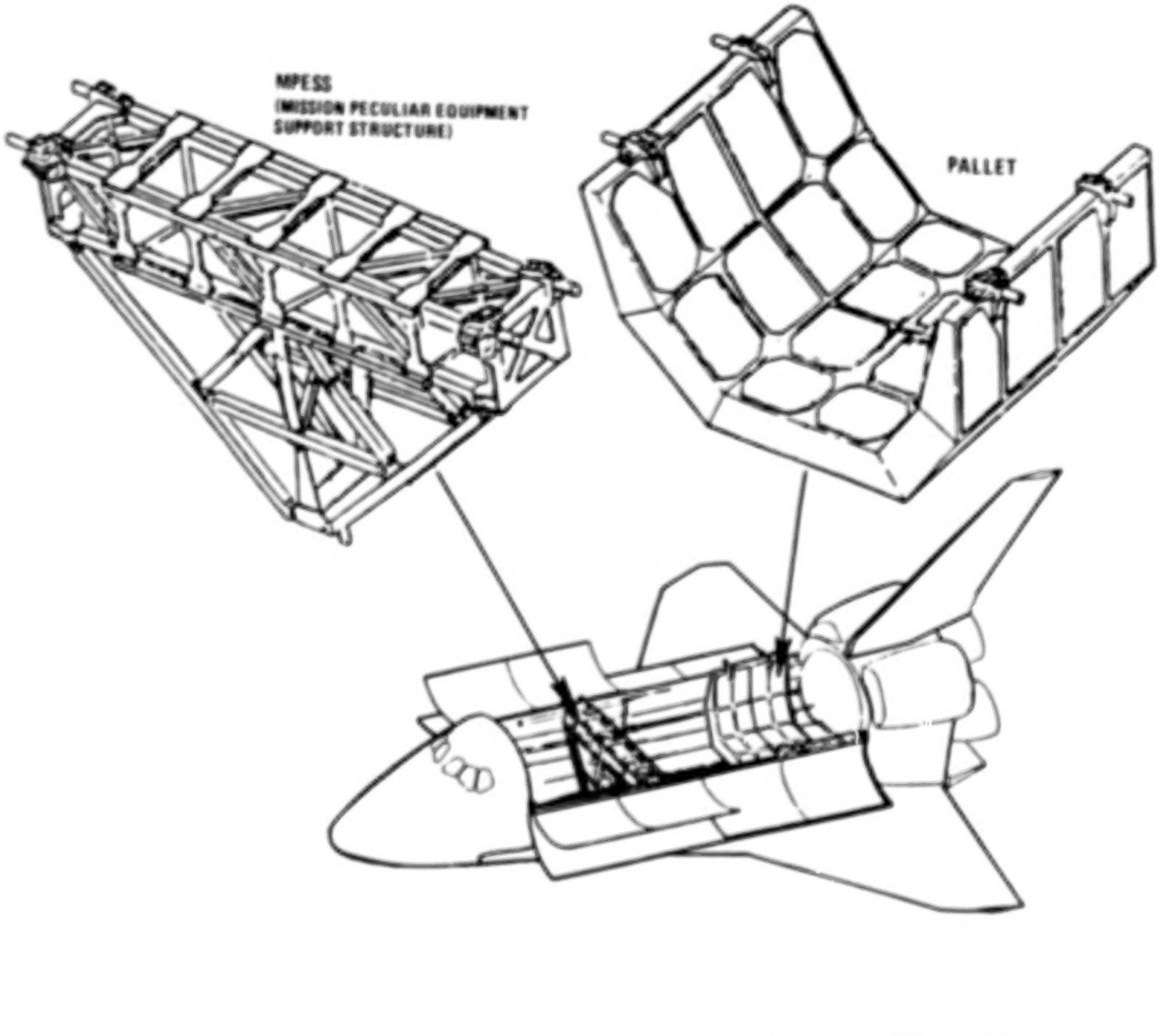


FIGURE 11 – ORBITER PAYLOAD BAY WITH CARRIERS INSTALLED

saddle and plates. Since the specific MPESS used for EASE/ACCESS had been sent to Marshall for major modifications, the MPE saddle and plates were also installed at Marshall. An additional MPE modification, flagged by the design agency, was the first piece of flight hardware to be installed at KSC. This modification consisted of a stiffener bracket which reinforced the carrier. As is the case when an unplanned change to flight hardware must be made, Marshall generated an engineering order and sent it along with the hardware and drawings as part of a mod kit. An engineering order authorizes a change to flight hardware and is always generated by the design center. KSC then wrote a test preparation sheet to perform the modification. Next, KSC installed the MPE foot restraint support structure using a test and assembly procedure. This was a planned part of MPE installation.

The remaining MPE hardware had to be installed later in the flow, because of late deliveries and because of interference with experiment installation. This MPE included four handrails for the EASE end racks, the foot restraints, the handrail assemblies for the foot restraints, and velcro for the MPESS top closure plates. The handrail assemblies for the foot restraints were installed during the week following initial EASE integration. The foot restraints, which were late delivery items from Johnson, arrived at KSC just prior to crew training operations. Three of the four foot restraints were installed for the crew training operations. The fourth foot restraint was installed afterwards, due to interference with ground scaffolding needed to reach the experiments for crew training. The foot restraint MPE and the foot restraints were installed per a test and assembly procedure.

The actual time it takes for hardware installation is usually longer than the amount predicted by the designers. This is because problems or new modifications (requested by the designer) often arise. KSC tries to prepare for this by ensuring that time estimates are conservative. Because of this, KSC was able to incorporate the many modifications to the EASE/ACCESS payload without impacting the launch date.

One modification occurred just prior to installation of the foot restraints. A mod kit was received from Marshall to increase the elevation of the foot restraint on the forward side (the EASE side) of the MPESS. The MPE interface between the MPESS and the foot restraint was changed. This modification was incorporated using a test preparation sheet.

A problem was then encountered with the orientation of the foot restraint on the forward side of the MPESS. The foot restraint was to be installed so that it directly faced the forward side of the MPESS. Based on the current MPE and foot restraint configuration, this could not be accomplished. A problem report was written to document this problem, and the appropriate personnel at Marshall and Johnson were consulted. After considering several complicated solutions, a relatively simple one was reached. This solution involved a simple reconfiguration of the foot restraint assembly. A field engineering change, which authorizes a change to the flight configuration, was written prior to hardware reconfiguration, and approval was obtained from Johnson. The foot restraint platform was reoriented with respect to the gimbal joint/probe assembly at a four bolt attachment location, and then the entire foot restraint assembly was reoriented with respect to the MPE interface clamp. This situation did not occur until very late in the flow, just several weeks prior to payload installation into the canister. Timely delivery of all hardware can help avoid such hardware problems late in the payload flow. This problem report was closed just one and a half weeks prior to the payload leaving the O&C building.

Two more MPE mod kits were also incorporated into the payload. The first modification called for the installation of two MPE handrails onto each of the two EASE end racks. The second modification added four velcro pads to the MPESS top closure plates to provide a storage location for the EASE cluster assembly pip pins.

EXPERIMENT INSTALLATION

After the ACCESS experiment was turned over to KSC, the bolts, nuts, washers, and other loose hardware were organized into kits, as part of the preparation for experiment installation. ACCESS was the first experiment to be installed. Because of the size and weight of the experiment canisters, the low bay crane was used, making these operations hazardous. After each component was attached to the crane hook, the area was cleared of non-essential personnel, the safety office was contacted, and the lift began.

The first item of ACCESS hardware to be installed was the node canister. A problem was encountered at the start when it was discovered that a small hole for an ACCESS alignment pin was missing from an MPE plate. NASA/Boeing personnel drilled the hole per the specifications in the drawing and proceeded with node canister installation. Afterwards KSC installed the two mast clamps and the assembly fixture. The assembly fixture was the first item to require use of the crane.

The diagonal strut canister was installed next. Another problem was encountered when the canister would not fit in the MPE plate cutout. As a result, KSC had to enlarge the cutout by filing five slots in the plate; this modification meant that the plate would no longer be "per drawing". Since it would take too long to have the design agency generate an engineering order to change the drawing and then forward the order to KSC as part of a mod kit, KSC chose to generate a field engineering change. Both a field engineering change and an engineering order can be used to authorize flight hardware modifications. The difference is that the engineering order is generated by the design agency and permanently accompanies the official drawing for that piece of hardware. The field engineering change, on the other hand, is generated by KSC and can be used to make hardware changes realtime. If a field engineering change is written, then the mission management team accepts the responsibility for amending the applicable drawing at a future date. The field engineering change generated for the MPE plate was quickly signed by the appropriate KSC personnel and by the design agency representative. NASA/Boeing then filed the needed slots and proceeded with the diagonal strut canister installation on the following day. The use of an field engineering change allowed the operation to proceed smoothly after all applicable parties had approved the change, without causing a significant delay.

The batten/longeron strut canister was the next item to be installed. When the door stop for the canister was installed and tested, it was discovered that shims had been sent to be used as needed, and several were in fact required. None of these spacers, however, where listed in the integration drawing. NASA opened a problem report since the door stop could not be properly installed without spacers. Next, NASA generated a field engineering change to add the shims to the integration drawing. Finally, NASA/Boeing installed the needed shims. The last item of the ACCESS experiment to be installed was the tool stowage assembly. No problems were encountered.

The EASE experiment arrived at KSC approximately one month after the arrival of the MPESS. Receiving and inspection, hardware turnover to KSC, and hardware kitting for installation were performed upon arrival. The majority of EASE installation was completed in two days. Since the EASE beams could be comfortably handled by several people, the facility crane was not required.

One problem encountered during the initial integration of EASE concerned the stiffness of the upper latch on the starboard restraint cradle. The problem was solved promptly by cleaning and lubricating the latch. Two weeks later, upon arrival of the pip pins and tethers, the four EASE clusters were installed. The base cluster and redundant jettison fitting were installed six weeks after initial integration.

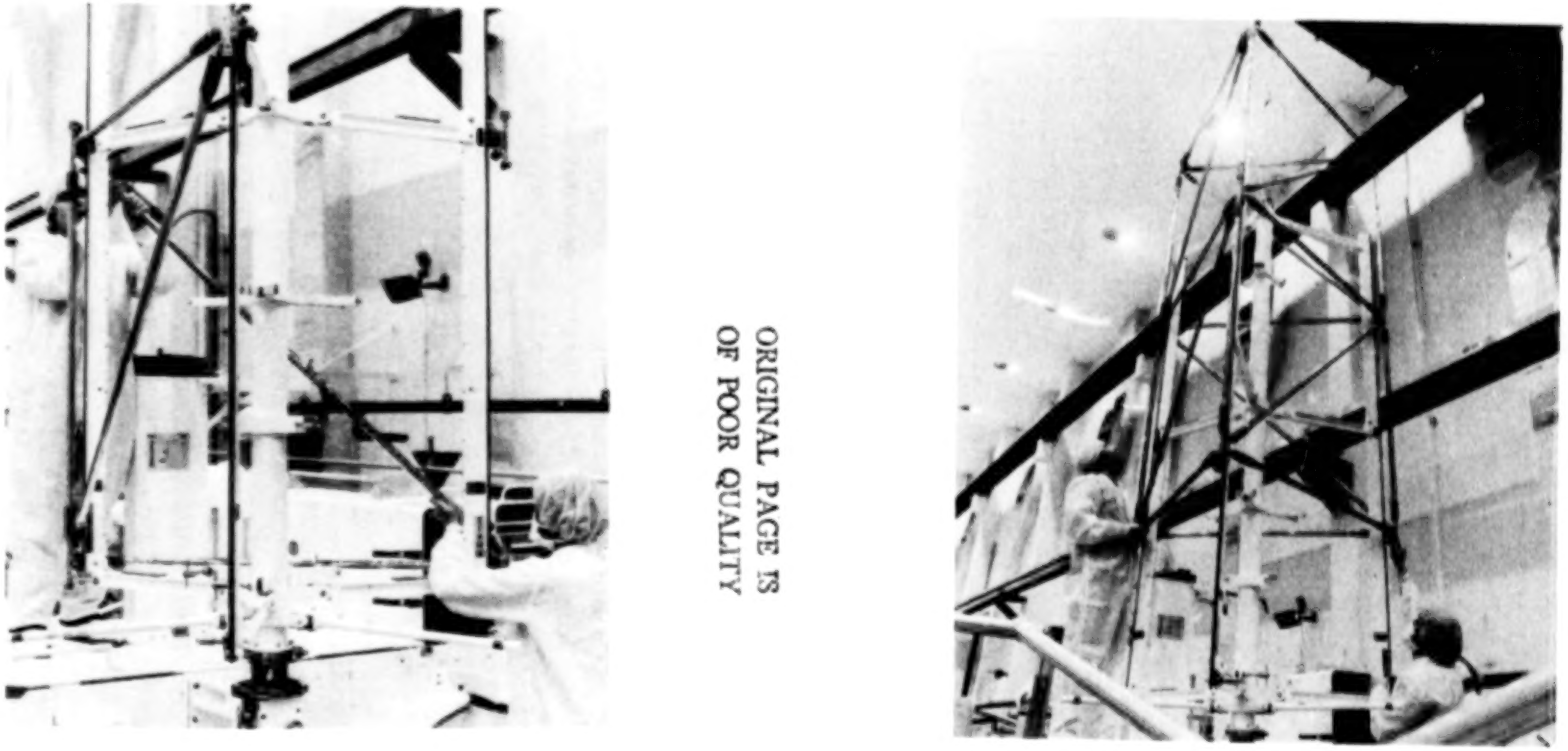
One requirement listed in the GIRD stated that KSC must verify the ability of the payload retention device to hold EASE cradles in the closed position. To perform this, KSC requested a payload retention device from the Johnson crew equipment office. The verification was performed as part of the EASE installation procedure.

NASA/Boeing generally perform any necessary hardware modifications once a payload has been turned over to KSC. A modification to the EASE hardware was requested by Marshall after installation was complete. This requirement was given to KSC in the form of a mod kit. The modification entailed the installation of threaded inserts into the joint cluster assemblies. The five cluster assemblies at KSC (four installed, one spare) were disassembled, modified, and reassembled. Much later in the payload flow, just prior to the crew training exercise, KSC received an additional mod kit for the changeout of hardware used to secure the ACCESS node canister. The ACCESS investigator travelled to KSC to observe the modification and was able to verify acceptable rotation of the canister.

EXPERIMENT TESTING

After experiment installation is complete, the experiments are functionally tested. For the EASE/ACCESS payload, ACCESS was tested in order to verify that all components worked together properly, but no functional testing of EASE was required at KSC. Although experiment interfaces are normally verified at KSC during functional testing, this was not possible with the EASE experiment. EASE was designed to be assembled only in zero-gravity, and any ground assembly had to be done in a water tank. In addition, no new interfaces were made at KSC that required testing. Therefore, it was agreed to by all concerned that no test of EASE would be performed at KSC. Since raising the ACCESS assembly fixture required the use of the crane, this procedure was hazardous. The ACCESS experiment, on the other hand, required a thorough checkout. Testing began by raising the fixture and verifying that it could be properly secured in the vertical position. The node canister, the diagonal strut canister, and the batten/longeron strut canister were checked next. Each strut was examined and the tools in the contingency tool kit were fit-checked. The contingency jettison hardware was operated to verify that it would work properly in flight. Every pip pin, latch, joint, and lever was cycled to verify smooth and proper movement. Finally, two bays were assembled and then stowed as shown in Figure 12. At the end of the functional test, the non-flight lifting hardware was removed from the ACCESS experiment.

As is normally the case, all operations are performed by NASA/Boeing personnel. The investigators are asked to be present to verify operations and



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12.1 – ASSEMBLY OF FIRST BAY

12.2 – COMPLETION OF TWO BAY ASSEMBLY

FIGURE 12 – ACCESS FUNCTIONAL TESTING

to provide trouble-shooting recommendations if a problem occurs. Because of the subjective "feel" criteria involved in assembling a space construction experiment, the ACCESS experimenter had provided an approximate range of pounds of force required to operate each item as a part of the procedure input. In several instances, NASA/Boeing questioned the feel of an item and the experimenter was asked to cycle the hardware and to make an evaluation. For each case, an interim problem report was opened as soon as a question arose. This type of report differs from a problem report in that the first identifies a potential problem or a problem that cannot yet be attributed to a specific item of hardware. The situation is evaluated during troubleshooting and all steps taken are documented on the interim problem report. If a specific problem is identified, then the interim report is upgraded to a problem report at which point the problem is fixed. If it is discovered that no problem exists and that the experiment does operate nominally, then the interim problem report is closed. For example, if the ACCESS experimenter indicated that no problem existed, as was the case with the latching of the first bay, then the report was immediately closed. If, however, the experimenter was not satisfied with the operation, as was the case with the force required to rotate the node canister, the interim problem report was upgraded to a problem report. The typical steps followed during problem identification and resolution are outlined in Figure 13. In the case of the node canister, several washers were removed and a lock mechanism was adjusted until the experimenter stated that the required force for rotation was acceptable.

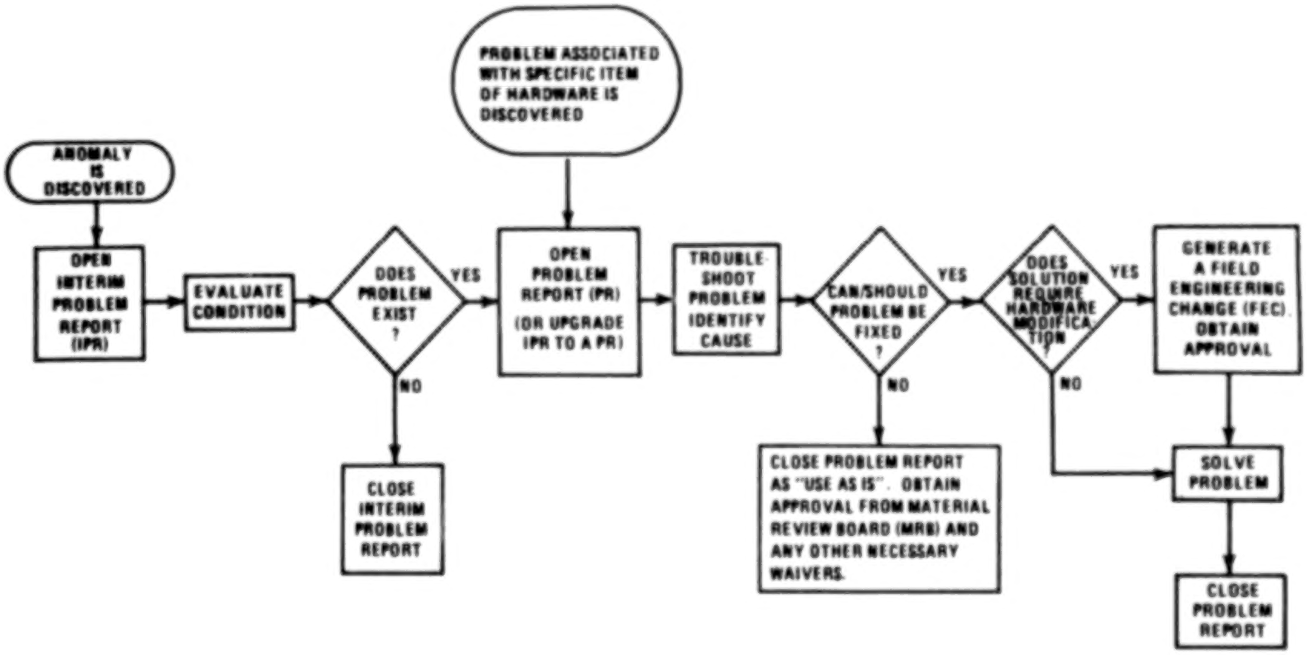
PROBLEM ASSOCIATED WITH SPECIFIC ITEM OF HARDWARE IS DISCOVERED
ANOMALY IS DISCOVERED
OPEN INTERIM PROBLEM REPORT (IPR)
EVALUATE CONDITION
DOES PROBLEM EXIST ?
YES
NO
OPEN PROBLEM REPORT (PR) (OR UPGRADE IPR TO A PR)
TROUBLE-SHOOT PROBLEM IDENTIFY CAUSE
CAN/SHOULD PROBLEM BE FIXED ?
YES
NO
DOES SOLUTION REQUIRE HARDWARE MODIFICATION ?
YES
NO
GENERATE A FIELD ENGINEERING CHANGE (FEC). OBTAIN APPROVAL
CLOSE INTERIM PROBLEM REPORT
CLOSE PROBLEM REPORT AS "USE AS IS". OBTAIN APPROVAL FROM MATERIAL REVIEW BOARD (MRB) AND ANY OTHER NECESSARY WAIVERS.
SOLVE PROBLEM
CLOSE PROBLEM REPORT

FIGURE 13 – STEPS FOLLOWED DURING PROBLEM IDENTIFICATION AND RESOLUTION

Normally, after all experiments complete their individual functional tests, the payload is operated together in an integrated test. This test is usually comprised of portions taken from the planned mission timeline. The specific time slices are chosen to represent the most active and demanding periods of the mission. If, for example, the experiments use electrical power to transmit data to the ground, then times where power use and data transmittal are at a peak are chosen. If the experiments involve manual operations by the crew, then a time which places maximum demand on the crew is chosen. With the EASE/ACCESS payload, each experiment was to be operated at a different time and neither experiment required the use of shared resources. Therefore, an integrated test was not required.

Crew involvement during payload processing enables the crew to gain experience with a payload's operation. Crew members are welcome at KSC for participation in regularly scheduled payload testing. This includes powered-up testing for those payloads with electrical interfaces. For most missions involving horizontal payloads, the crew participates in all integrated tests and in some functional tests. Unless a separate item is placed in the GIRD requesting an additional crew training session or an inflight maintenance procedure walkdown, no time for such a test is built into the KSC processing schedule. As for all experiments, the crew was welcome to participate in the ACCESS functional test. Unfortunately, they did not attend this test. Later in the payload flow, after the ACCESS experiment closeout had already been performed, a special test was requested by the mission manager. With many payloads being processed in parallel, and KSC resources (including personnel) being shared by all payloads, the schedule usually does not allow for such arrangements.

Fortunately, after coordinating resources scheduled by other payloads, a crew training session was worked into the processing flow. This test enabled the crew to check out the EASE and ACCESS experiments and the MPE. A test preparation sheet was written for the crew training exercise. In order to perform the crew training operations, several ACCESS flight screws had to be removed and the non-flight lifting hardware for the assembly fixture had to be reinstalled. During training with the EASE experiment, the mission specialists removed and replaced each beam, one at a time, and verified the operation of the beams/clusters. The ACCESS portion of the training was hazardous since the facility crane was used. The mission specialists assembled two bays of the ACCESS experiment and also fit-checked the contingency tools. Additional equipment had to be shipped to KSC to support the crew training operations. This equipment consisted of the EASE harpoons and special connector, and the ACCESS tool boards. During crew training, the mission specialists verified the interfaces between this equipment and the experiments. Also, the foot restraint locations and heights were visually checked. The crew members then performed a sharp edge inspection of the payload. Upon completion of the crew operations, the ACCESS experiment closeout was reperformed.

During the crew training exercise, the crew members discovered several hardware changes that they wanted incorporated. These changes were documented as crew squawks, problem reports specifically requested by a crew member. In addition to the usual signatures required for closure, a crew squawk must be signed by a flight crew representative before the problem report can be closed. Three major crew squawks concerned the forward foot restraint orientation, the ACCESS node canister rotation, and the EASE base cluster top pip pin operation. Two minor crew squawks included requests for markings on the wrenches in the ACCESS contingency tool kit and for numbers on the node canister buckets.

The problem with the foot restraint orientation was fixed with hardware reconfiguration, as discussed previously. Difficulty in rotating the node canister was again flagged. Extensive troubleshooting was performed on the node canister hardware in order to obtain smoother rotation. The solution was reached by reducing the torque on the twenty bolts attaching the shroud to the MPESS, and by lubricating the rollers on the node canister caps. The reduction in torque required a field engineering change for approval, since it altered the hardware configuration from that indicated on the integration drawing. The problem report on the EASE base cluster addressed stiff operation of the top pip pin. To correct this problem, the pip pin hole was enlarged to drawing specification. At the same time, the bottom pip pin hole was also enlarged. Smooth operation was obtained for both pip pins at the base cluster/jettison fitting. The markings requested on the wrenches and the numbers requested on the node canister buckets were made using a special pen with approved flight ink. Field engineering changes also had to be generated for these last two problems.

PAYLOAD CLOSEOUT

After all experiment installation and testing is complete, the payload is ready to be prepared for transfer to the orbiter. Payload closeout operations begin prior to leaving the O&C building and include sharp edge inspections, payload envelope clearance checks, weight and center of gravity measurements, cleaning, inspection, and closeout photographs.

Payload sharp edge inspection is particularly important for Shuttle missions that have a planned EVA (Extravehicular Activity). The ACCESS experiment and associated MPE were checked for sharp edges immediately following its functional test. Two sharp edges were found on the MPE and were rounded. ACCESS was then closed out for flight. As stated previously, the ACCESS closeout had to be reperformed after the crew training session. A sharp edge inspection of the entire payload was performed during crew training operations. No additional sharp edges were found on the payload. Although it is not required, KSC encourages the flight crew to perform their own payload walkdown and sharp edge inspection during the scheduled closeout.

Just prior to EASE/ACCESS closeout operations, a last minute modification was received from Marshall to install thirty-two logos onto the payload. A few logos could not be installed due to hardware interference.

Another closeout operation that is normally scheduled is payload envelope clearance checks. A computerized optical alignment system is used to determine if the payload is within the orbiter payload bay dynamic envelope, and to ensure that the payload will not interfere with the orbiter and/or with other payloads. During envelope checks for EASE/ACCESS, the outboard handrail for the top foot restraint was found to be outside the payload envelope by four inches. A problem report was written and was referred to the mission management team for resolution. The MPE handrail had to be removed from the carrier the day before payload transfer to the canister after weight and center of gravity measurements had been performed.

Payload cleaning occurs just before final closeout inspection. During this final inspection the payload is verified to be clean, to have all non-flight hardware removed (unless the hardware is scheduled to be removed later in the flow), and to have no obvious anomalies. Closeout photographs, such as the one in Figure 14, are also taken to document the payload configuration.

The final closeout operation performed prior to payload installation into the canister is normally the payload weight and center of gravity measurements. This is a hazardous operation, due to the use of the facility crane. The entire payload is lifted with the crane and is set down so that each trunnion rests on a load cell. These load cells are installed on an adjacent trunnion support fixture. The payload weight and center of gravity (x and y axes only) are then calculated by KSC. The EASE/ACCESS payload weighed 4364.5 pounds and the center of gravity was at x=788.49 and y=-5.85 in orbiter coordinates. These numbers take into account the handrail that was removed.

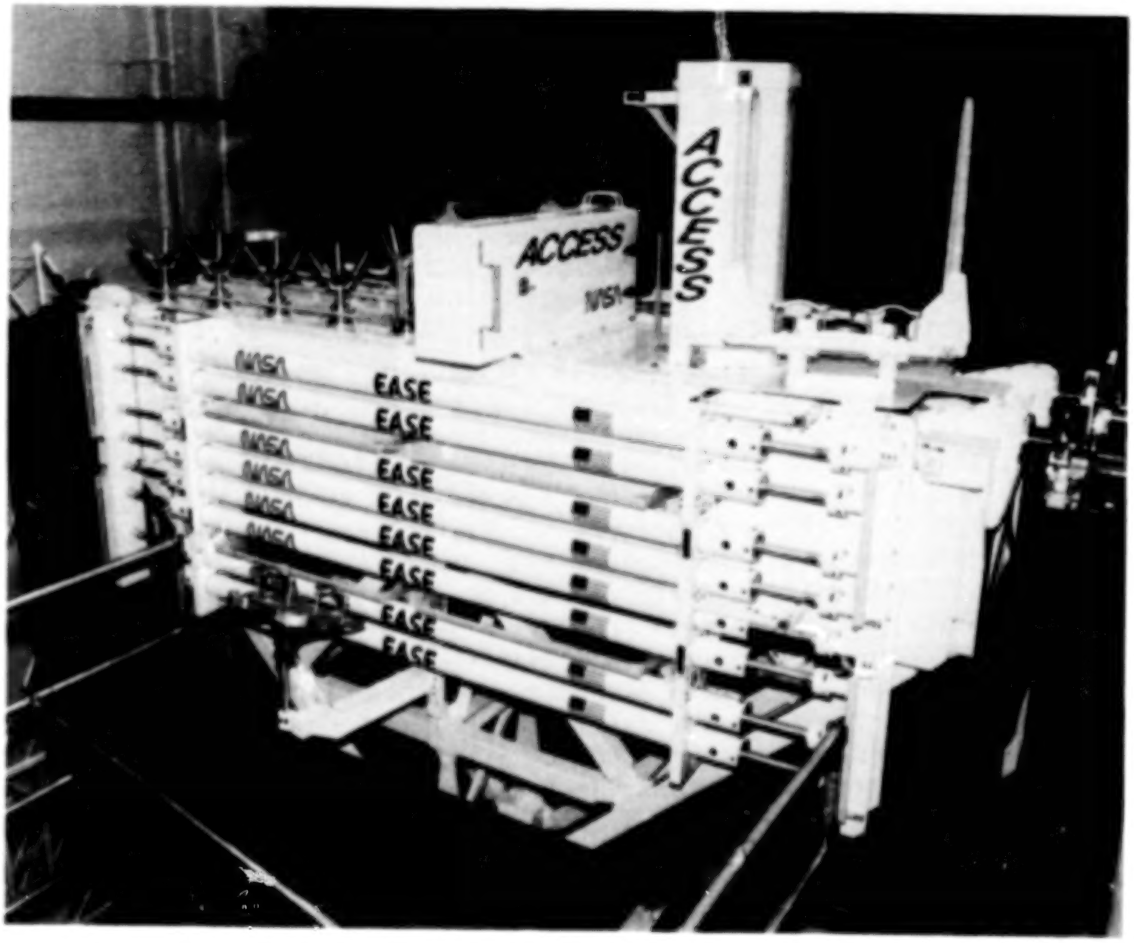

FIGURE 14 – EASE/ACCESS LEVEL IV CLOSEOUT

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ORBITER OPERATIONS

After the completion of payload closeout, the carrier is prepared for Level I integration. Level I includes all payload operations that involve the orbiter or orbiter simulators. The first Level I operation occurs in the CITE stand in the O&C building. The CITE stand simulates orbiter interfaces, and interface verification testing is usually performed when the payload is at this stand. The payload is again secured and then transferred to the orbiter at either the Orbiter Processing Facility (OPF) or the pad. If any experiment to orbiter interfaces need to be verified, then another payload interface verification test is performed, this time using the actual orbiter. For example, if a space construction experiment has sensors that will be transmitting data to the ground during the flight, then the data stream is sent through the actual communications loop and verified. Such a test may involve sending the data from the experiment through the orbiter (either at the pad or the OPF) to the tracking data relay satellite, to White Sands Test Facility, to Goddard Space Flight Center, to Johnson Space Center and back to Kennedy Space Center. In this way, the entire loop is verified. Since EASE/ACCESS required no interface verification testing and had no electrical interfaces with the orbiter that needed verification, the payload was transferred directly to the orbiter after Level IV closeout.

At the same time that the payload is being processed in the O&C building, the Space Shuttle is being prepared for flight in the OPF. After the orbiter is ready and any payloads that must be installed horizontally are in place, the vehicle is rolled out to the Vehicle Assembly Building (VAB). In this facility, the two solid rocket boosters are mated to the external tank. When the orbiter arrives, a special handling fixture is attached to it, and the orbiter is rotated from the horizontal to the vertical position, as shown in Figure 15. The vehicle is then mated to the external tank. The entire Space Shuttle is then rolled out to the pad aboard the mobile launcher platform. Once the Shuttle arrives at the pad, it is ready to receive any remaining payloads.

Payloads are transported from the O&C building to the orbiter in the environmentally controlled payload canister. Most horizontal payloads are installed into the orbiter in the OPF. The OPF is the facility where orbiter refurbishments and flight preparations occur. Some horizontal payloads and all vertical payloads are installed into the orbiter at the launch pad. Reference Figure 7 for the complete horizontal payload processing flow.

The EASE/ACCESS horizontal payload was installed at the pad. EASE/ACCESS was first installed into the canister in the O&C building, with the canister in a horizontal position, as shown in Figure 16. The facility crane was used for this hazardous operation. The canister then traveled to the VAB and was rotated to the vertical position, as shown in Figure 17.1. In this vertical position, the canister traveled to the Vertical Processing Facility (VPF) in order to pick up the three satellites that were flown on the same mission. In Figure 17.2 the mission 61-B payloads are shown in the canister at the VPF. The VPF is similar to the O&C building in that both are the sites of Shuttle payload processing. The VPF, however, only accomodates vertical payloads; whereas, the O&C low bay only accommodates horizontal payloads. Following transfer of the three satellites from the VPF into the canister, the canister traveled to the pad.

Once at the pad, the payloads were transferred from the canister into the payload changeout room using a special handling mechanism. Payload canister

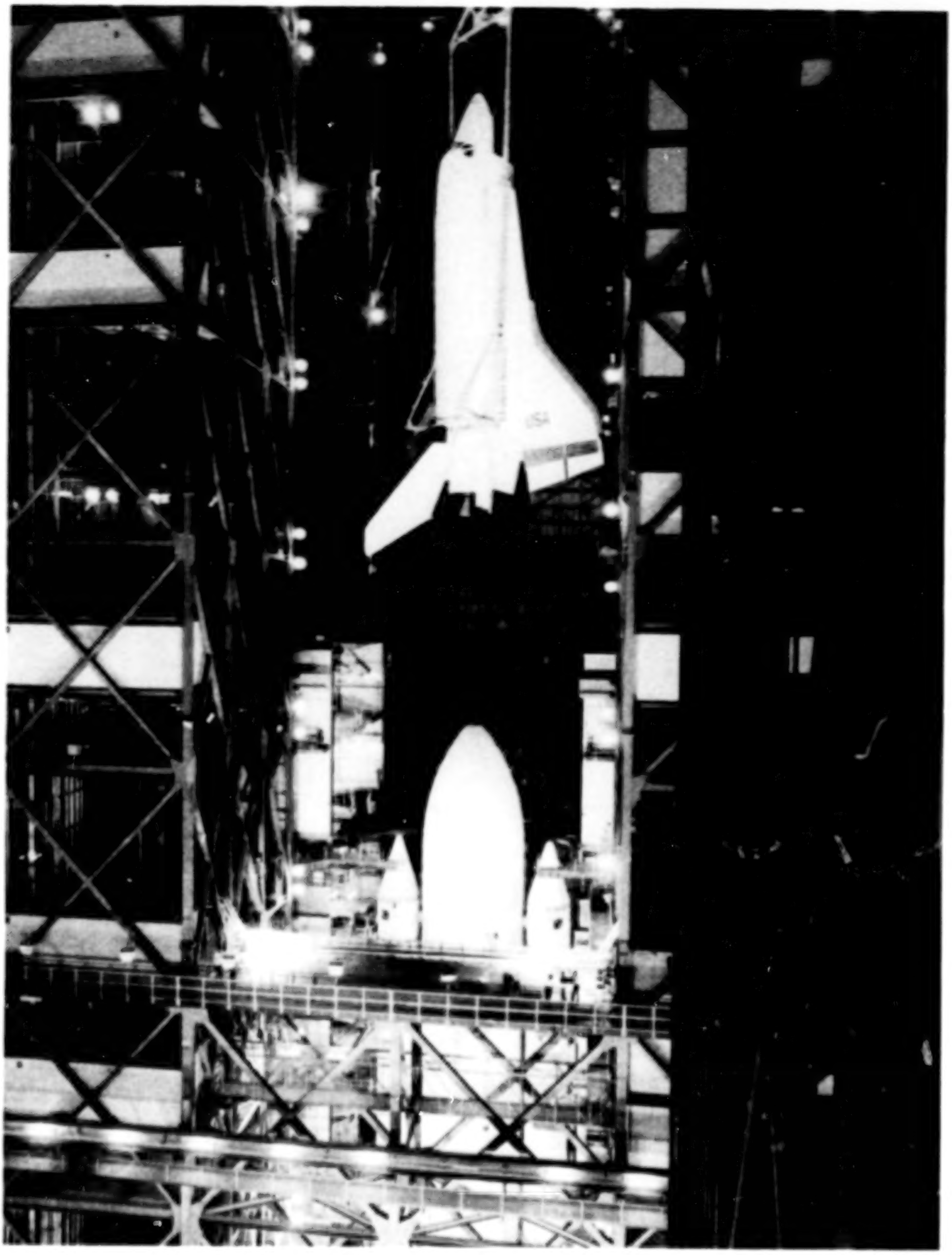

FIGURE 15 – ORBITER MATING WITH EXTERNAL TANK AND SOLID ROCKET BOOSTERS

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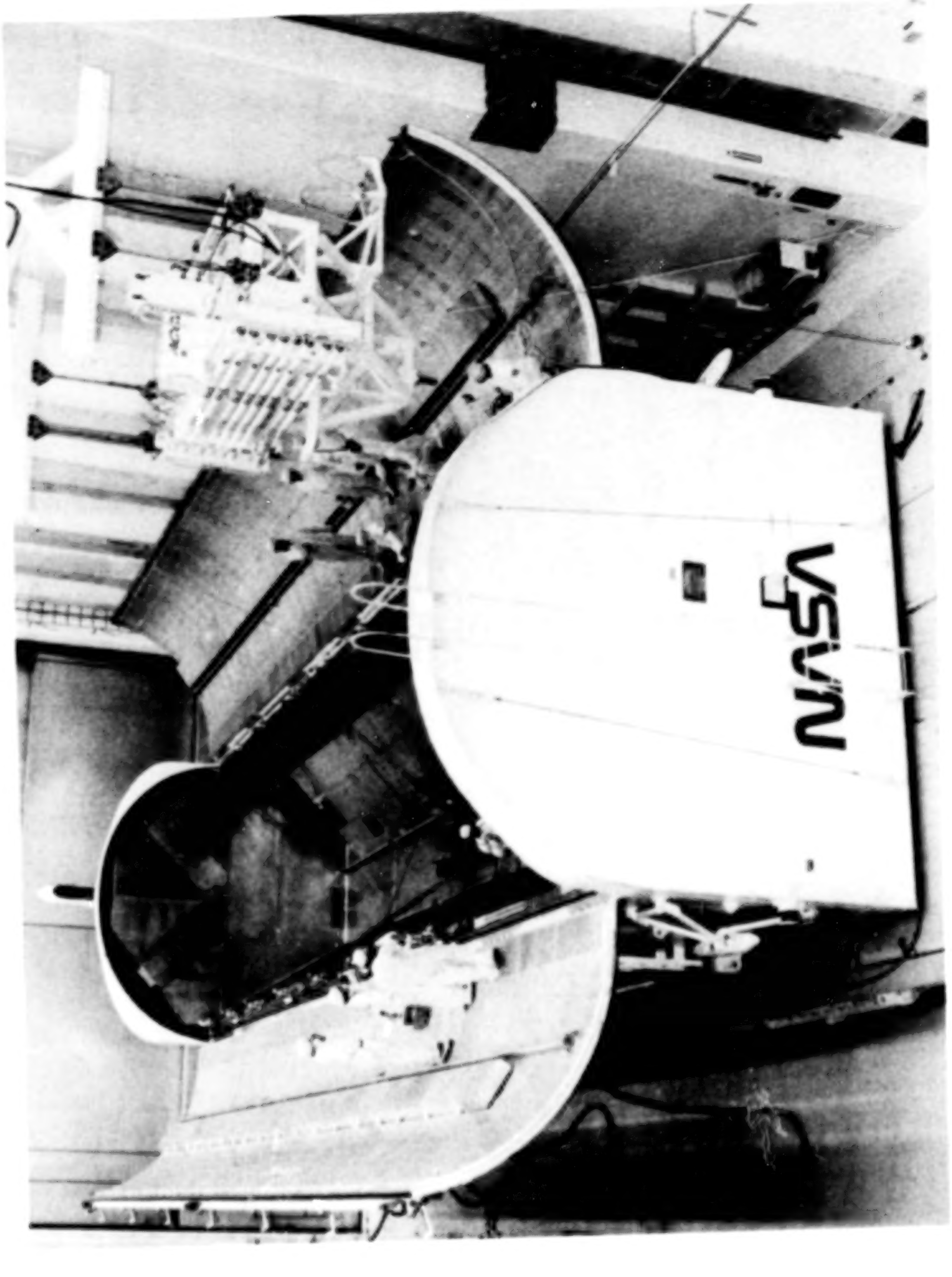
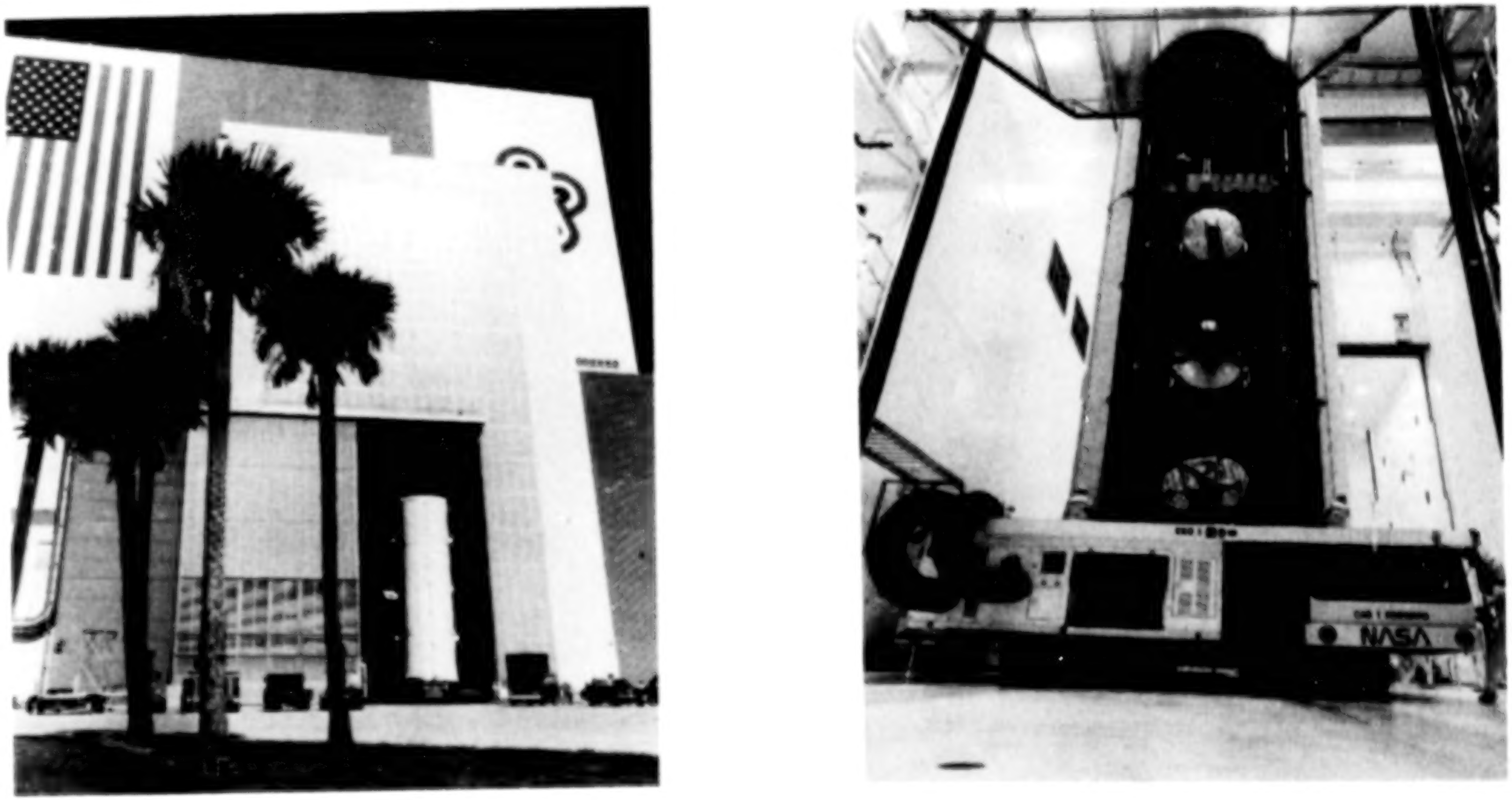


FIGURE 16 – EASE/ACCESS INSTALLATION INTO PAYLOAD CANISTER



17.1 – CANISTER LEAVING THE VEHICLE ASSEMBLY BUILDING (VAB) AFTER ROTATION TO VERTICAL

17.2 – MISSION 61–B PAYLOADS IN CANISTER AT VERTICAL PROCESSING FACILITY (VPF)

FIGURE 17 – PAYLOAD CANISTER OPERATIONS

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installation at the pad is shown in Figure 18. After the payloads were transferred into the changeout room, the EASE/ACCESS MPESS required light cleaning. The rotating service structure, which houses the changeout room, was then rotated to the orbiter, and the payloads were installed into the payload bay. Lockheed fulfilled the one payload-generated orbiter requirement by verifying the electrical bonding between the MPESS and the orbiter. Just prior to the closing of the payload bay doors, EASE/ACCESS was inspected for

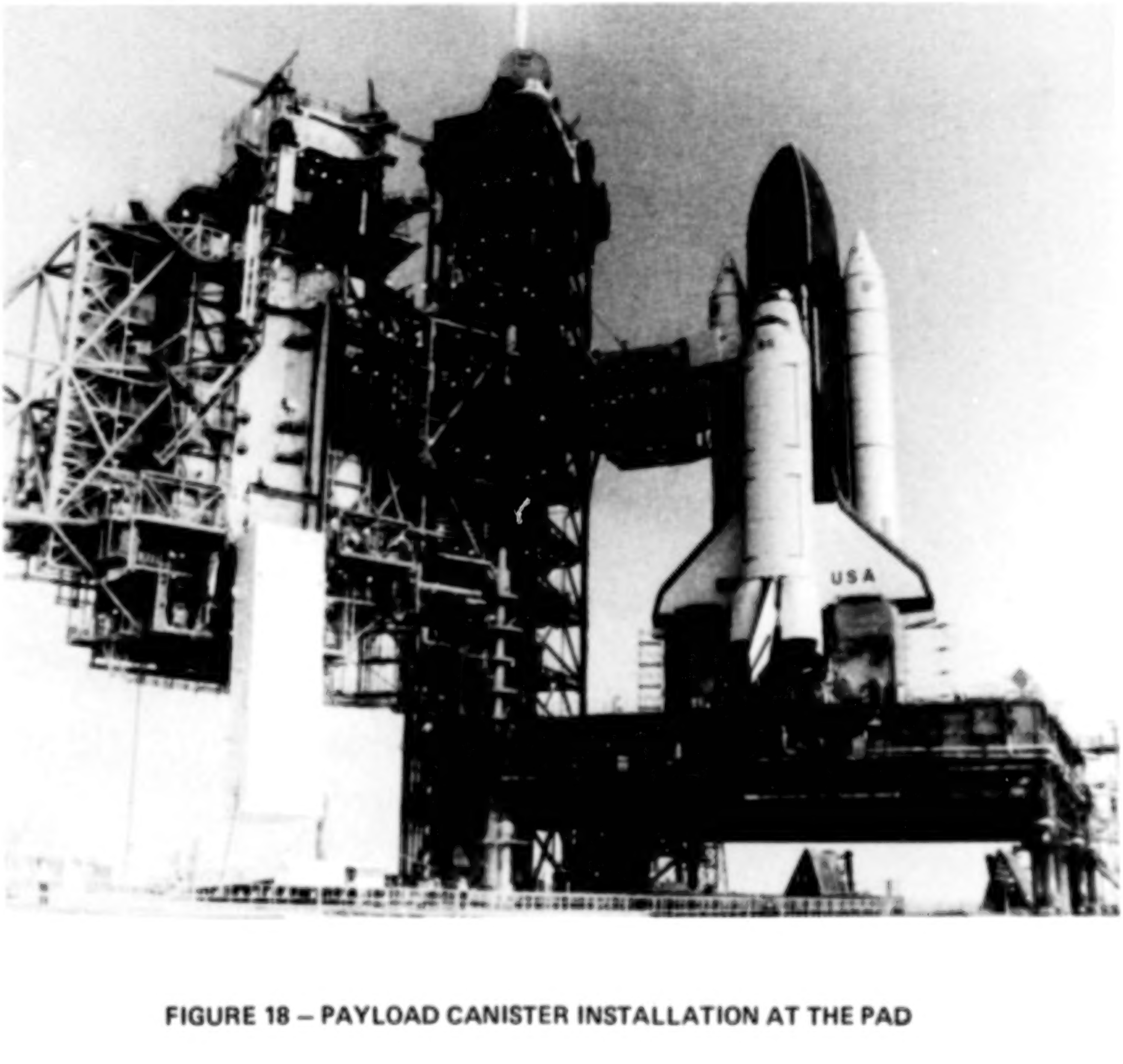

FIGURE 18 – PAYLOAD CANISTER INSTALLATION AT THE PAD

anomalies and final pad closeout photos were taken. Figure 19 is one of the pad closeout photos.

In addition to payload hands-on operations, several readiness reviews are conducted at KSC prior to launch. The first of these is the Payload Readiness Review. The purpose of this review is to verify the readiness of the payloads for integration with the orbiter and to verify the readiness of the orbiter for payload installation. For the STS-61B mission, the Payload Readiness Review was conducted the day before the payload was installed into the canister. The next scheduled review is the Launch Readiness Review. This review verifies the readiness of the Shuttle, the payload, and all launch and landing support systems. All test anomalies and unsolved problems are

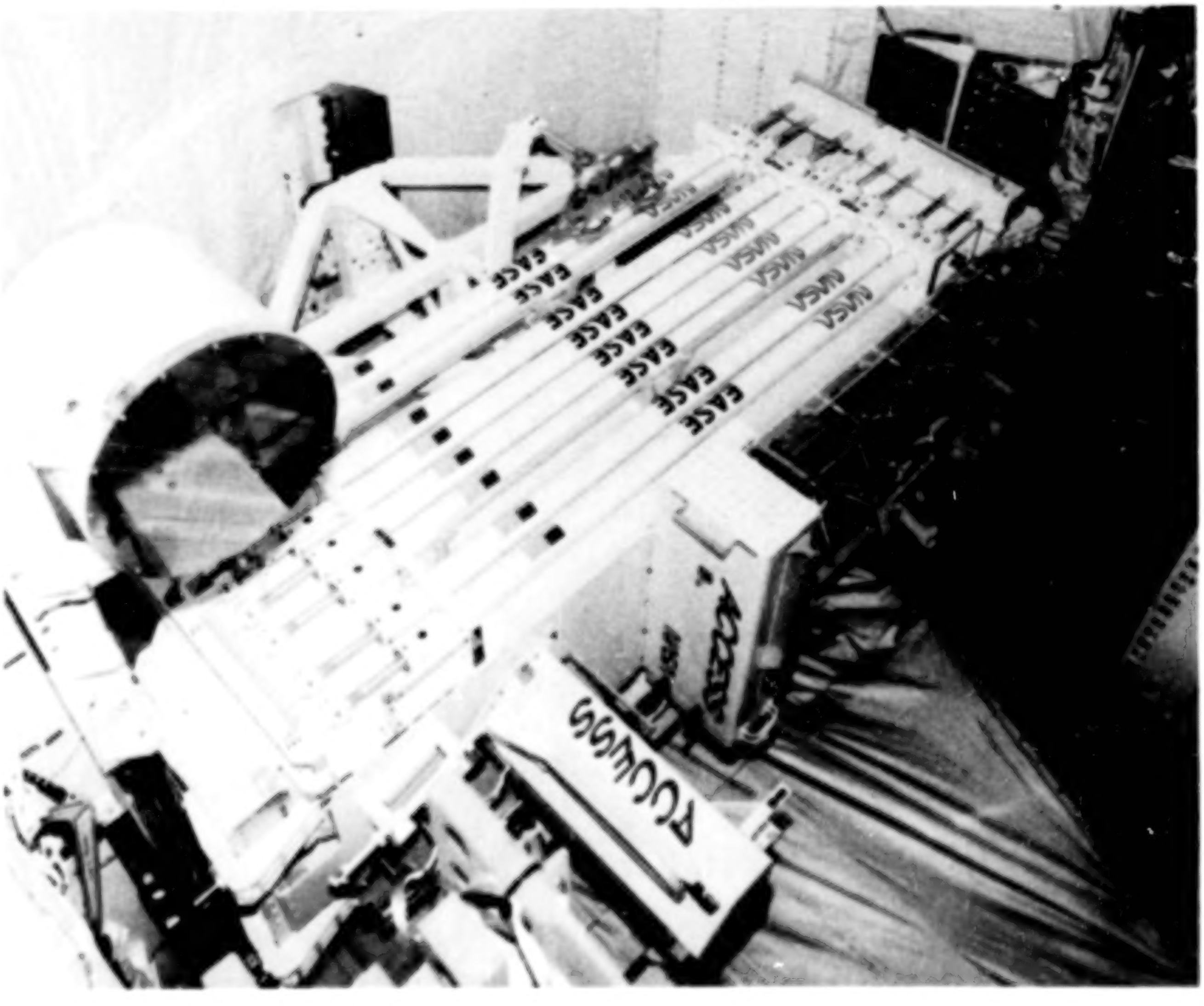

FIGURE 19 – EASE/ACCESS PAD CLOSEOUT

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discussed at this meeting. The final review is the Flight Readiness Review, which verifies the readiness of the entire STS system and all operational plans and procedures. Mission 61-B launch, which was a night launch, is shown in Figure 20.

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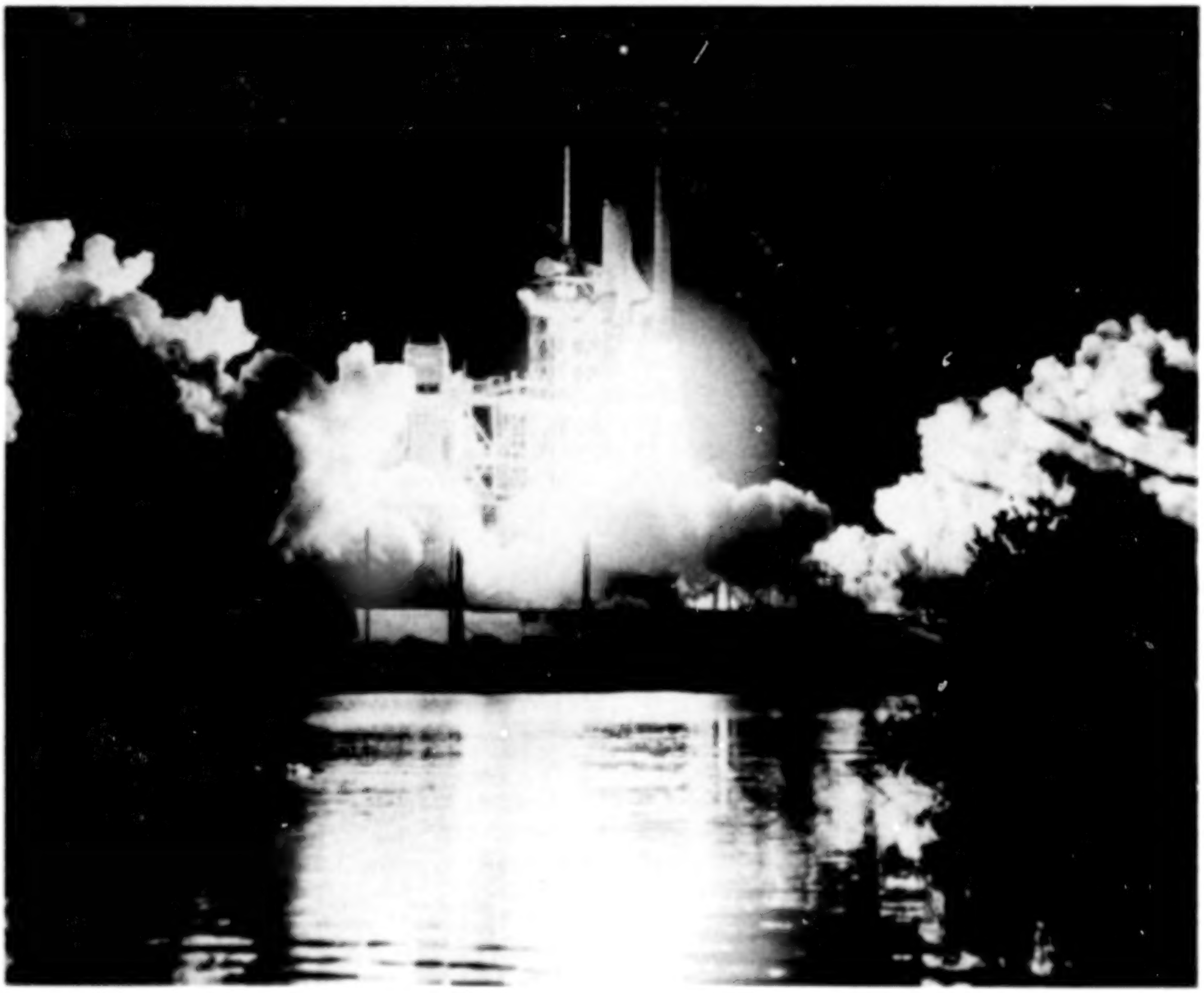

FIGURE 20 – MISSION 61–B LAUNCH

POSTFLIGHT

After the mission, the orbiter lands at either KSC or Dryden Flight Research Facility. Mission 61B landed at Dryden. Normally, there is no access to the payload bay while the orbiter is at Dryden. If during initial formulation of the GIRD and LSSP, however, it is agreed upon that hardware inside the payload bay is time-critical and must be removed at Dryden, then special arrangements can be made for NASA/Boeing personnel to enter the payload bay at Dryden and remove the time-critical items. All plans must be made well in advance and must be agreed to by KSC. Since the payload bay doors cannot be opened at Dryden, this activity requires KSC personnel to enter through the crew compartment and traverse out the airlock into the bay. Special ladders and platforms need to be fabricated and installed for this activity. Non-flight lights and air cooling hoses also need to be routed into the payload bay. Because of the complexity involved and the short time it takes the orbiter to return to KSC aboard the Shuttle carrier aircraft (approximately 1 week), hardware removal at Dryden is avoided whenever possible. In any case, whether at Dryden or at KSC, experiment hardware is always removed by KSC personnel. The orbiter is shown landing at KSC in Figure 21 and is being ferried back to KSC in Figure 22.

If the orbiter lands at KSC, none of the above operations are required. Entry into the payload bay is available within 48 hours after landing. For payloads that are not time-critical, such as EASE/ACCESS, the entire carrier is removed from the payload bay after the orbiter is returned to the OPF. The carrier is placed in the payload canister and transported to the O&C building where it is installed in a Level IV stand. The individual experiments are then deintegrated from the MPESS and returned to the payload mission manager. If time-critical items need to be removed in the OPF before the MPESS is returned to the O&C, access is available. All special requirements, however, such as for early removal of experiment hardware, must be stated in the GIRD and must be agreed to in the LSSP.

Deintegration of the EASE and ACCESS experiments was accomplished in three days. All hardware removal was performed per test preparation sheet. Deintegration of all MPE hardware (including the foot restraints) took approximately one week. After the experiments were removed by NASA/Boeing personnel, the items were officially turned over to the mission manager and then shipped from KSC to the experimenters. After the MPE hardware was deintegrated, it was turned over to the mission manager. The foot restraints were then shipped to Johnson and the remaining MPE hardware was shipped to Marshall. After all payload hardware had been removed, the MPESS was moved to an offline lab in the O&C building.

At this point in the flow, the carrier is inspected and all nonconformance items are corrected. For the EASE/ACCESS mission carrier, paint had chipped off in certain areas of the MPESS and excess epoxy residue, used for securing bolts, remained after the experiment and MPE hardware had been removed. A problem report was written, the residue was removed, the paint was touched-up, and the MPESS was brought back to flight configuration. The MPESS now remains in the offline lab until the next payload is ready to be installed onto it. At that time, the MPESS is moved to the Level IV stand, and the integration process begins again with the installation of the MPE and experiment hardware.

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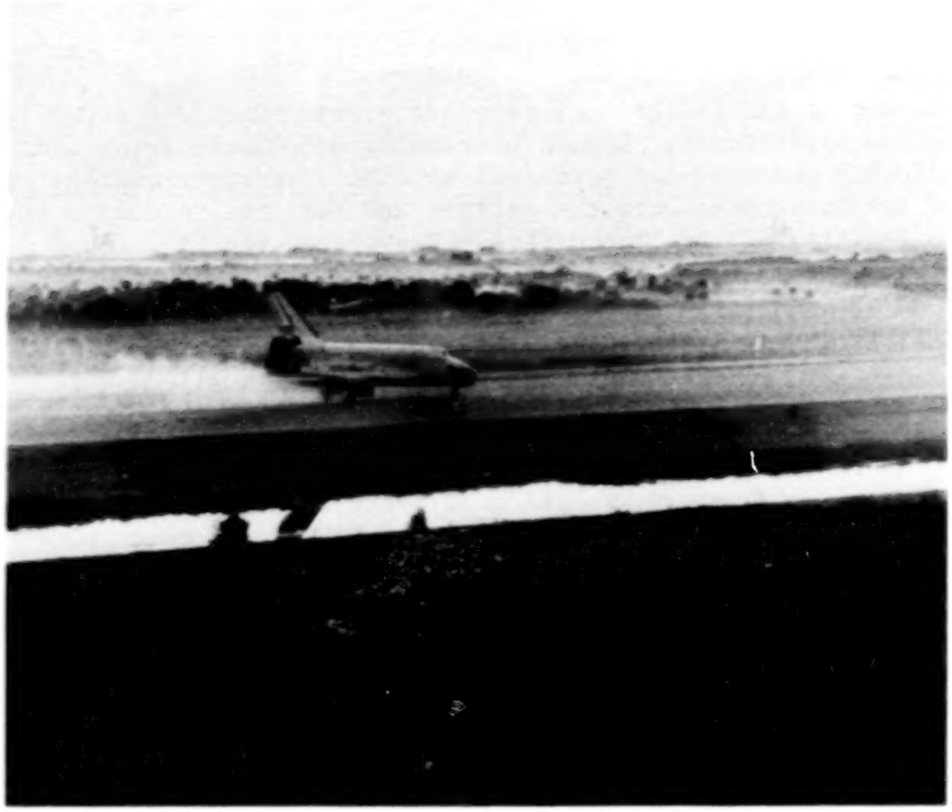

FIGURE 21 – SHUTTLE ORBITER LANDS AT KSC

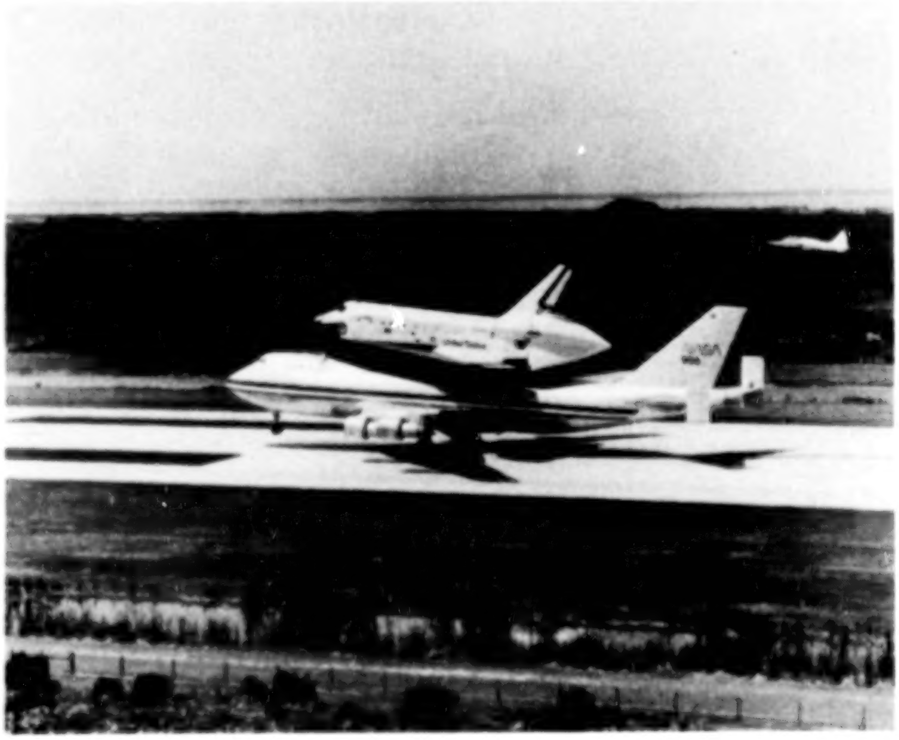

FIGURE 22 – SHUTTLE ORBITER IS FERRIED BACK TO KSC FROM DRYDEN

CONCLUSION

The processing of EASE/ACCESS can serve as a good example for future space construction experiments. Ground processing and installation into the orbiter for all such payloads are performed at KSC. The experiments arrive separately and are integrated onto the carrier and into the Shuttle. All interfaces are verified at the launch site. The processing flow is standardized, yet flexible enough to accommodate individual payload requirements, as was demonstrated by EASE/ACCESS integration. Minor problems can arise, however, during integration. Recommendations for investigators are detailed in Figure 23. Investigators can decrease the likelihood that common problems occur by ensuring that all processing requirements are clearly documented in the GIRD, by verifying that their experiments are completely built and thoroughly tested prior to shipment, by carefully reviewing all integration drawings and checking to see that every item to be installed is included, by submitting detailed procedure inputs to KSC for every planned operation, by supporting any scheduled operation on an as-needed basis, by delivering the hardware on schedule, and by fully informing KSC about the exact status of the hardware at delivery. With the opportunities for working in space increasing, many more types of payloads will be flown aboard the Space Shuttle. By planning ahead and working together with KSC personnel, payload preparation for flight can be a smooth and valuable step to reaching orbit and ensuring mission success.

- STATE (IN GIRD) ALL EXPERIMENT REQUIREMENTS (E.G., INSTALLATION, TESTING, MAINTENANCE, CALIBRATION).
- STATE (IN GIRD) ALL KSC RESOURCES REQUIRED (E.G., OFFLINE LAB, SPECIAL HANDLING DEVICES, FLUIDS, GASES, POWER).
- COMPLETE EXPERIMENT FABRICATION, THOROUGHLY TEST EXPERIMENT, AND OBTAIN ALL BASELINE DATA PRIOR TO SHIPMENT.
- PROVIDE WRITTEN PROCEDURES TO KSC ENGINEERS.
- STATE IN THE DELIVERABLE ITEMS LIST ALL ITEMS TO BE SHIPPED TO KSC.
- DELIVER ALL EXPERIMENT HARDWARE ACCORDING TO THE AGREED-UPON SCHEDULE.
- PROVIDE COMPLETE DATA PACKAGE TO KSC AT TIME OF HARDWARE DELIVERY.
- CAREFULLY REVIEW INTEGRATION DRAWINGS AND KSC PROCEDURES.
- ADDRESS ANY DISCREPANCIES RESULTING FROM PAYLOAD REVIEWS.
- PARTICIPATE IN PAYLOAD MEETINGS.
- SUPPORT KSC OPERATIONS AS REQUIRED.
- ENSURE THAT ALL EXPERIMENT HANDLING EQUIPMENT IS PROOFLOADED TO KSC SPECIFICATIONS AND THAT ALL OTHER SAFETY REQUIREMENTS HAVE BEEN MET PRIOR TO HARDWARE ARRIVAL AT KSC.
- DURING EXPERIMENT DESIGN PHASE, CONSIDER ONE-G ACTIVITIES TO BE PERFORMED AT KSC, AS WELL AS ZERO-G ACTIVITIES IN FLIGHT.

FIGURE 23 – RECOMMENDATIONS FOR INVESTIGATORS

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PANEL DISCUSSION
PAYLOAD INTEGRATION FOR SMALL CARGO BAY PAYLOADS

Participating in this panel discussion are Richard E. Valentine, EASE/ACCESS Mission Manager; Robert S. Wolf, Design Engineer for EASE Experiment; Ana M. Villamil, Ground Operations Manager; John F. Rogers, Lead Design Engineer for the ACCESS Experiment; Charles E. Chassay, Payload Integration Manager for the EASE/ACCESS Experiments; Gerald E. Hall, MSFC EASE Project Manager; Gerald W. Hawkins, Project Engineer for the EASE/ACCESS Experiments; and Robert Hill, Teledyne Brown Engineering Contract Manager for the EASE/ACCESS Mission Integration.

QUESTION:

Has there been any work to standardize the hardware end of the procedures?

ANSWER, ED VALENTINE:

When you get into a situation like the Space Station operation where you've got repetitive flights, you're going to do a similiar kind of function. We did not - we have not gotten into that. Certainly we got into repetitive operation in this one mission, but not in the sense of flight repetition. I could make a comment that we talked about things like you've heard discussed by several speakers - the fact that we had to move foot restraints so that they would accommodate an individual. Well, obviously if you're going to do that over a long period of time, you may have to come up with a standard kind of location. You might have to accept some kind of nominal and not configure it for each flight very specifically. I'm just using that as an example. I don't know if that's possible or not but I think it would be that kind of thing. Bob Wolf, do you have any comments on that? Your experiment dealt with the repetition to a good extent. Do you have any comments?

BOB WOLF:

Well, first I have to ask you if you're talking about the repetitive flights of identical hardware or repetitive operations on-orbit. Well, if you look at the integration process as being primarily the production of paper which allows you to achieve the objectives of safety and compatibility that you're trying to address, then you prepared the paper once and set up the procedures once, and you just go through the same thing each time. While Charles is talking about an integration paper overhead of about this big, he didn't talk about the 12 iterations or 5 iterations or whatever it took to get that final product in. If you do that once, the integration process, I think, would be significantly easier the next time around.

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ANA VILLAMIL:

As far as the integration at Kennedy Space Center (KSC) is concerned, once we process an experiment, we use the same installation and testing procedures for future flights of that experiment, and we just modify the procedure based on the changes to the experiment. Also, we have generic procedures to perform standard operations such as determining the weight and center of gravity (cg) of a mission peculiar equipment support structure (MPESS), or performing the cleanliness inspection and the sharp edge inspection of a payload. We use these procedures over and over.

ED VALENTINE:

We have a payload that we've flown once and will probably fly again that we call the Material Science Laboratory that flies material processing experiments. It will fall in that category. We use the same hardware over and over again by changing samples, furnaces and things like that - that being the only change. The repetitive flights of that will be a lot easier and a lot less expensive than the initial one.

CHARLES CHASSAY:

When a new customer comes in on a payload assist module (PAM), which is a deployment module for a satellite, there's very little documentation changed, and that's the best way to do the business. It's a proven method of actually deploying it. All of our people have seen it once before so it cuts down on the effort to support the mission, and that's important to us for two factors: it relieves some of the people to continue to work in future space flights as well as the fact that we've gone through these things, we've fine tuned them, so we'd like to see repetitive type payloads actually fly. I don't know if we've answered your question or not, but if the documentation is not appreciably changed from mission to mission, that really works to our advantage.

QUESTION:

Will any of the EASE hardware be used in Space Station construction?

ANSWER, BOB WOLF:

No, I don't think anyone is planning on building the Space Station structure out of EASE beams. What we were trying to do is gather productivity and other human factors related data, such as learning rates on space structure assembly. What we would have loved to do is assemble something the size of the Space Station to get data. Of course, once you do that, you don't need the data anymore, but the reason that we have 64 pound beams that are 12 feet long is that they allow us to model larger structures that we just can't afford to carry up in the payload bay for that kind of experiment. Picture someone assembling something like an ACCESS truss from a fixed work site, and then having to add that onto another existing structure. And so in that sense, the ACCESS construction of the truss and EASE manipulation of the truss simulations kind of complement each other.

QUESTION:

Do you expect to build the Space Station out of either the ACCESS or EASE structure?

ANSWER, ED VALENTINE:

No. The answer is no. These experiments were technology experiments that provided basic data, as George explained this morning in the flight demonstration program, that's what he supports. Both of these experiments were purely technology experiments to provide basic data, and from that, you would design whatever specific design you need for a space station or other large structure. So they were definitely technology based experiments.

QUESTION:

Was any consideration given to evaluating the structural response of either the EASE or ACCESS experiments?

ANSWER, ED VALENTINE:

No. That was never a part of the EASE or ACCESS experiments. Obviously the data would have been very good but such an evaluation was outside the scope of what was approved for flight.

QUESTION:

Ana, you mentioned there were some problems when the hardware got to KSC in terms of the processing - there were problems in modifications that KSC had to make. What were some of those problems?

ANSWER, ANA VILAMIL:

Each experiment had approximately a dozen problems and the mission peculiar equipment (MPE) hardware also had a dozen, but let me say that that's a very good record. We've had experiments at KSC that have had over 100 problems with just one experiment. Some of the minor problems encountered on the EASE/ACCESS payload were: 1) paint was scratched on a handrail when it was received; 2)sharp edges that weren't apparent in the drawings were found; and 3)one of the cutouts in the MPE plates had to be enlarged slightly. All of the problems involved minor modifications. Although we hope that no problems are going to occur, we know that some will, and we're prepared to follow-up and resolve those problems once the hardware is at KSC.

QUESTION:

How do you modify flight hardware?

ANSWER, ANA VILAMIL:

We have an extensive approval loop. There are basically two ways to approve a change to flight hardware. The first way applies if we run into a problem at KSC. For example, if something doesn't fit and we have to cut the hardware or round off an edge. We use what we call a field engineering change. We make a sketch of the change we want to make, and have the field engineering change approved. We have the appropriate people at KSC sign it, plus the

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mission manager and also the design agency. Once everyone agrees to the change, then we can go ahead and modify the hardware. Usually, we can obtain the approvals and begin to modify the hardware within one day. The second way to approve a flight hardware change occurs when the change is initiated by the mission manager. In this case, the mission manager initiates an engineering order (EO) and forwards it to KSC. We then perform the work. Ed will now talk about this method.

ED VALENTINE:
Let me use as an example the thing you mentioned about the handrail that interfered with the remote manipulator system (RMS) - you remember Jerry Hawkins and Ana Vilamil commented on that. They found at the Cape, in one of the clearance tests, that one of the handrails would likely impact the RMS. Ana fed that information back to us at Marshall. That's obviously going to take a design change, and that's our decision on what to do about that. I got with my contractor who designed that, and he did an analysis - dynamics analysis. We did an extensive analysis over about three days and determined that it probably would not hit it, but the risk was too great - then we had to make a decision. He made an EO drawing change and we got that back down to Ana, and that's a basis then for her action. She wrote a procedure to remove the obstruction and changed the flight configuration.

QUESTION:
Who pays for it?

ANSWER, ED VALENTINE:
The mission manager - mission integration pays for that analysis to make that engineering change. The actual change, if it's done at the Cape as it was done there, comes out of the KSC processing flow - it's part of that processing flow.

CHARLES CHASSAY:
I would like to add to that if you don't mind. Whenever changes occur to flight hardware that has been through the payload safety process and if those changes affect the flight safety or the payload safety process, the customer needs to have those changes identified to the payload safety panel. We're most interested in finding out whether or not that hardware change may affect or control in any way the payload safety hazard controls. If there are materials that would be changed or added to the hardware that may affect its outgassing properties and possibly other contents in the Orbiter cargo bay, our materials personnel are most interested in that. Changes do occur at KSC, which is the last opportunity to correct some of these problems. We are concerned with what happens in flight with these changes as they may have adverse effects on other cargo bay payloads.

QUESTION:
It was mentioned that the Kapton on the ACCESS rods had been ripped. Any idea what caused that, and are any changes going to be made the next time this flight occurs?

ANSWER, JOHN ROGERS:

The cause of it, we feel like, was probably due to the movement of the struts, especially in returning the struts to the cannisters. The tolerances between the diameter of the locking collars and the guide tubes they went into, allowed the tubes to rotate down but increased the possibility that the Kapton could be torn as the struts were returned to the cannisters. That was a hazard we expected to see. As far as Space Station construction elements are concerned, I don't know at this point. I know that the Space Station truss will consist of five-meter bays and will be erectable. At this time, I'm not aware that any materials have been baselined and I don't think Kapton will be used on Space Station struts.

QUESTION:

I don't know whether to address this to Mr. Hawkins or Mr. Chassay, but I'd like to hear some elaboration on the flight rules that were in effect during the process - two specific processes, when the ACCESS was up and being built, and secondly when the crewman was on the manipulator foot restraint (MFR) which is attached to the end of the RMS. What were the flight rules concerning the vernier reaction control system (RCS) and the primary RCS during that time period, and how did you develop those?

ANSWER, GERALD HAWKINS:

When we were erecting the ACCESS experiment, we had the primary RCS inhibited, and we were maintaining attitude with the vernier RCS. There were no constraints on the crew on the RMS or while they were assembling the structure. The flight rule that was imposed due to our analysis was that during the second EVA while the crew had a beam out of the assembled ACCESS structure, it essentially crippled the assembled ACCESS structure where it wouldn't carry sideloads during this phase of the experiment. When the beam was out of place, the Orbiter did go to a free drift attitude and did not use either the vernier or the primary thrusters.

QUESTION:

How did you address vernier failure during the time that the crew was out on the RMS or the time the beam was out of the truss. How did you address a single vernier failure?

ANSWER, CHARLES CHASSAY:

We ran mathematical simulations to examine that possibility. In fact we ran a case that we call the "angry astronaut case" to excite the structure to where it would drive the ACCESS structure to failure. A crewman would have to pulse a thruster, I think for three or four minutes (yeah, it was a long period of time) in a given sequence - you know a given rythmic pattern - in order to excite the structure to where it would break. I guess that's the way we treated any failure scenario. We first determined what kind of a failure would cause it to break and if that was a creditable problem that could happen.

QUESTION:

Suppose you had a crew member on the MFR on the RMS, and you had a lost device and you had to go after it when you had vernier failure. Did you address this type of failure at all or did you just groundrule out certain failures by flight rules?

ANSWER, ED VALENTINE:

To go after a piece of hardware, you'd have to use primary thrusters I believe. We made certain ground rules if a piece was lost. We would first reconfigure the experiment and the crewmen into a safe configuration before we would initiate any maneuver to go after a piece of hardware.

QUESTION:

Did you make any design changes to accomodate neutral buoyancy?

ANSWER, ED VALENTINE:

No, I don't think so. You have to put flotation on so the parts that are free are neutrally buoyant of course. Other than that, there's no special consideration given. In other words, flight configuration is possible.

QUESTION:

So you really just added some material to the basic structure to make it neutrally buoyant or....

ANSWER, BOB WOLF:

That's pretty close. In the case of the EASE beams, we put a double o-ring bulkhead on each end of the beams, just inboard of the harpoon holes, so that the beams were filled with air, and that provided sufficient flotation. To make up for the difference between the weight of the bulkhead and the little volume of trapped water by the harpoon hole, the mass of the fitting at the end was increased by one pound at each end so that the dynamic properties were the same. For the clusters, all we did was to add flotation. The hardware that was all bolted to the MPESS wasn't going anywhere anyway so it didn't need to be neutrally buoyant. It was identical.

QUESTION:

Did you have any problem with leakage or the sort of thing that would cause the buoyancy to change and consequently affect your test in the neutral buoyancy chamber?

ANSWER, BOB WOLF:

The hardware has to be neutrally buoyant for each run. The beams never leaked. Flotation gets changed by anything that's got flotation on it - whenever it's no longer neutrally buoyant. That stuff gets fine tuned all the time.

QUESTION, GEORGE LEVIN:

I'd like to address this to John Rogers and to Bob Wolf.

While the hardware and the experiment was almost 100% successful, we did have two anomalies that occurred with the hardware in flight - one with ACCESS and one with EASE. Would you address what happened and also, from a "lessons learned" concept, what would you do differently?

ANSWER, BOB WOLF:

On the EASE experiment, I recall that we had a redundant jettison device on our base cluster by which the base cluster could be separated from the MPESS pallet, and we did that during the second EVA. The problem occurred when the pip pin was supposed to be reinserted and just wouldn't go. There are two reasons for this. One is that the requirement to separate the structure intentionally, and therefore intentionally reattach the structure, was never made clear before critical design review (CDR), so that jettison capability was used in a way it wasn't designed for. In all cases where there were pip pins designed to be cycled, a good size chamfer was placed on the hole in which the pip pin was inserted. We did not have that on our base cluster, but I think that probably would have solved the problem.

JOHN ROGERS:

On ACCESS, the annomaly concerned the locking features on the redundant latches on the diagonal cannister which would not function after the first EVA period. Again, there were redundant latches. I guess if they had it to do over again, they would probably design that latch so that that could never happen. The button apparently rotated around and the malfunction occurred due to the inability to see that button, its positioning. In a redesign activity, we would design the latch so that the button could not rotate, therefore eliminating this potential failure mode.

Q> CANNOT UNDERSTAND COMMENT FROM AUDIENCE.

ANSWER, ED VALENTINE:

That was all in ACCESS funding for the EASE/ACCESS unique hardware. As you heard today, in some cases we maximize the use of hardware already in the inventory as with MPESS, to keep the cost down; so there's no new cost to buy a new MPESS obviously. That cost dealt with the integration function that we do at Marshall, which includes providing the new hardware needed on the MPESS that Bob Hill described - the plates and the foot restraints and the hardware was bought with that. Plus the integration analysis that we do at Marshall included the development contract for the EASE with MIT - so it funded the MIT effort to EASE and also funded the ACCESS effort here at Langley. As you heard, most of the ACCESS work was done in-house, but the funding that was required came from that. They went through other elements of integration of that sort. NASA payload funds don't get transferred within NASA to pay another office for those kinds of functions.

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ANSWER, BOB WOLF:

I can expand on your question a little bit. We were curious about that ourselves. How much of this paid for the hardware, and how much of this paid for the paper. There were times when we thought the paper cost was a higher percentage than it really turned out to be. MIT got $860,000 roughly. It was distributed to members in percentages roughly as follows, and these numbers are in our final report: it's about 15% for the science aspects - data reduction, the science associated with developing the hardware experiment; 45% for the hardware production and manufacture and purchase of materials, etc.; 20 - 25% for documentation costs, and 15 - 20% for the cost of doing the engineering, for designing the hardware itself.

ANSWER, CHARLES CHASSAY:

Just to add to that Ed, the Draper Lab flight control study, at approximately $150,000 would have come out of that. I guess there were some small monies probably earmarked for the JSC contractors support, for the Weightless Environment Test Facility (WETF) tests at Marshall.

ANSWER, ED VALENTINE:

We didn't pay for the reimbursement, did we Charles, for all the astronaut time and all the WETF testing. There were some unique contracting costs when they had to bring suits, equipment or whatever to MSFC for WETF testing. They were small costs, like $10,000 for each of the tests. That's the magnitude of the costs and there are other NASA institutional costs that we don't pay. We don't transfer funds within NASA to cover those costs.

Q> CANNOT UNDERSTAND COMMENT FROM AUDIENCE.

ANSWER, ED VALENTINE:

If the whole cost of a reimbursable non-NASA payload were to be reimbursed, it would be substantially larger than that.

Also the agency has certain agreements with the departments as well as certain cooperative agreements. NASA has an interest also in science development. It's quite possible that we would engage in a cooperative agreement between our organizations, and somehow work out price for the flight activities.

QUESTION:

Was there any experimental verification of the structural dynamics analysis for the fully assembled structures in either the case of EASE or ACCESS?

ANSWER:

No there was not.

QUESTION:

So we don't really know how good our fully assembled structural dynamics models were for these configurations?

ANSWER:
That's absolutely correct.

And the hardware itself was not instrumented in flight to allow observation of any response to flight control type activity.

In the case of ACCESS, we did some ground testing on a fully assembled structure to try to verify our stiffness matrices that we used in our analyses. That gives some credibility to what went on, but nothing was verified in flight.

QUESTION:
Was anything done in the neutral buoyancy facility such as shape testing or anything?

ANSWER, BOB WOLF:
No, not in neutral buoyancy.

We can't really do that because the water drag just damps everything out too much.

QUESTION:
Were there any annomolies noted on the flight test associated with electromagnetic interference (EMI) in this structure to indicate that maybe the resistivities were not what you thought they would be in the fully extended case of ACCESS. Were there any coronas observed or anything like that in flight?

ANSWER, JERRY ROSS:
There were some observations from the ground on interruptions of real time data coming out of the Shuttle suits which were monitored back down to the ground during the period of time that we were in the immediate vicinity of essentially fully erected ACCESS. There was some interruption of the radio frequency (RF) link from the suits to the Orbiter, but other than that, we saw no effects with the Orbiter.

QUESTION:
I don't want to beat a dead horse, but I want to get something straight. With regard to the cost that you mentioned a moment ago, did I understand you correctly that the 3.5 million dollars did include the prorated costs of the personnel within NASA with some minor exceptions, like the EVA time from various centers (LaRC, MSFC, KSC and so on)? Was that included in the $3.5 million, or is that considered support, and the $3.5 million went for some sub-contrators and things of that nature?

ANSWER, ED VALENTINE:
It did not include the overhead cost of NASA government personnel. No, it did not include the government personnel salaries. Those are mainly contractor costs. There is little overhead charge for government personnel at all centers, so it includes mainly contractor costs.

QUESTION:

That, for example, does not include the cost of engineering that was done, the design of it and so on?

ANSWER, ED VALENTINE:

Well yes. In our case, that's primarily contractors, the actually engineering. So it does include the engineering for the most part, because that was a contract activity.

QUESTION:

Is the fracture control board involved in looking at this structure?

ANSWER, GERRY HAWKINS:

The fracture control board does address all structures every flight. For the initial flight, they look at all the structures.

QUESTION:

Do they get involved with every payload? For example, if there is a commercial payload, what is the role of the fracture control board?

ANSWER, GERRY HAWKINS:

Let me put it this way. They get into all critical structure - that is, any structure that could damage something. The fracture control board will not get involved with the internal structure of a module which would not damage the Orbiter if it broke. However, the board does address all critical structures.

As a kind of follow-up, if you're reflying a payload and you have changed any part of your hardware that might initiate some critical new structure, you have to come back in and resubmit the fracture critical information as part of the payload safety program.

The fracture assessment does address the life of the hardware also. A part may be good for two or three flights, but then has to be reassessed. The performance of additional non-destructive testing of the hardware may be required after a given number of flights.

GEORGE LEVIN:

If that completes the questions, we'll close out this panel discussion. Thank you.

N88-10878

RESEARCH AND DEVELOPMENT AT THE MARSHALL SPACE FLIGHT CENTER NEUTRAL BUOYANCY SIMULATOR

Vygantas P. Kulpa
Neutral Buoyancy Simulator
Marshall Space Flight Center

Space Construction Conference
Langley Research Center
Hampton, Virginia
August 6-7, 1986

INTRODUCTION

The Neutral Buoyancy Simulator (NBS), a facility designed to imitate zero-gravity conditions, is located at the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center (MSFC) in Huntsville, Alabama. In the facility's million-gallon water tank, weightlessness is simulated by placing weights or floats on the test subjects and test articles so that they are neutrally buoyant.

Flight experience indicates excellent correlations between neutral buoyancy simulations and weightlessness. In addition, simulating space operations by this technique allows an entire set of procedures to be evaluated without interruption. Two space construction experiments flown aboard a recent NASA mission relied heavily on research done at the Neutral Buoyancy Simulator. During the two years prior to flight, extensive testing was done for the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS).

MSFC NEUTRAL BUOYANCY SIMULATOR APPLICATIONS

The first neutral buoyancy simulator, which had a 7.6 meter (25 foot) deep water tank, opened at MSFC in the 1960's when little was known about space, especially about Extravehicular Activity (EVA) or space walks outside a spacecraft. Thus, it served as a laboratory for studying how neutral buoyancy simulations could be used to mimic space operations.

The current 12 meter (40 foot) deep, 23 meter (75 foot) wide water tank opened in 1968 to support the growth occurring in the space program. Early research in this facility centered on investigating how neutral buoyancy could be applied to space operations and to the development of equipment and techniques for conducting underwater simulations. General research was conducted by the NBS staff to examine spacesuit capabilities and demonstrate hardware concepts and procedures for diverse activities such as astronaut transportation systems, spacecraft repair, and large space structure assembly.

Today, research at the NBS falls into two categories: maintaining the facility to support researchers from NASA and outside the agency and conducting in-house research to advance the state of the art in zero-gravity simulation. The simulator is used primarily to select concepts, verify preliminary hardware designs, develop EVA procedures, train personnel, and support missions real time.

The facility has been vital to the success of a variety of NASA missions. In 1985, the NBS was designated a National Monument because of the role it played in developing the repair procedures for Skylab in 1973 when the spacecraft's sunshield was damaged during launch and its solar arrays failed to deploy. The simulator continues to be used for developing EVA procedures for servicing and repairing spacecraft. Tests are in progress to ensure that the Hubble Space Telescope and the Space Station are designed for long-term operations in space.

In the Shuttle era, the Neutral Buoyancy Simulator is a research laboratory used by NASA and the aerospace community for engineering studies of hardware. In 1985, the first structures (EASE and ACCESS) were built in space after many hours spent in the MSFC tank, selecting the structural concepts, developing assembly techniques, verifying EVA procedures, and training the crew. As we enter the Space Station era, NASA and aerospace contractors are testing concepts for station components in the Neutral Buoyancy Simulator. The facility provides an environment where they can evaluate such complex operations as patching a habitable module in the event that it is punctured in orbit. In addition, concepts can be developed for the station's framework.

NASA and aerospace contractor research activities are escalating, and therefore, the NBS is used primarily to support this research. However, the simulator staff continues to conduct in-house research to improve simulation quality. This in-house research often results in benefits for NASA and other customers. For instance, the facility staff designed and installed an underwater version of the Remote Manipulator System (RMS). It is the only functional RMS available for neutral buoyancy training, and it has been valuable in practicing procedures that cannot be simulated elsewhere. This underwater system allowed the EASE/ACCESS crew to practice complex procedures in which astronauts assembled the structures while being moved and positioned by the RMS.

The NBS record over the past 18 years shows that the staff has devised innovative solutions to challenging problems. This has given NASA and its contractors the assurance that hardware and procedures that work in neutral buoyancy simulations will work successfully in space.

NEUTRAL BUOYANCY SIMULATOR OPERATIONS

The MSFC NBS has many other unique features besides the manipulator arm. It is the largest NASA facility of its kind. This enables the tank to accommodate large space structures like the 12 meter (40 foot) tall ACCESS tower or other very large satellites like the Hubble Space Telescope. The tank is equipped with a full-size mockup of the Shuttle payload bay where mockups of flight hardware can be mounted for tests. Pressurized spacesuits and an underwater Manned Maneuvering Unit (MMU) are available for use in simulations.

A control room adjacent to the water tank provides a work place for customers during tests. The control room is equipped with consoles and television monitors showing five views inside the tank, communications equipment, and an audio/video taping facility.

The experience of the NBS staff is a valuable asset in determining potential uses for the facility. For tests, which are joint endeavors between government and private industry, the NBS staff works with the user, with leadership taken by one or the other as the situation demands. By working together as a team, the test benefits from both the expertise of the NBS staff and the user.

In the most successful efforts, such as the EASE/ACCESS program, the user works closely with MSFC personnel from the beginning of a project. For example, to ensure safety, a NASA engineer inspects user hardware prior to delivery. This inspection not only guarantees that the hardware meets safety standards but helps the user resolve other problems before the hardware is shipped. Working together early in the project's development establishes close ties between the user and NASA personnel and gives the NBS staff the opportunity to inform the user of lessons learned from previous neutral buoyancy tests. Requirements for using the facility are outlined in the MSFC Neutral Buoyancy Information and Requirements document (1).

The MSFC team also helps the user by filling critical positions required for tests. The NBS provides test subjects who are scuba and pressure suit qualified; they are trained to evaluate space equipment designs objectively and develop operations procedures. MSFC also supplies other support personnel, including utility divers, safety divers, underwater photographers, systems engineers, timekeepers, recompression chamber engineers, lock engineers, inside diving attendants, and medical officers.

Prior to a test, the NASA team prepares the facility for the test by performing final safety checks and suiting up the test subjects in Shuttle Extravehicular Mobility Units (EMUs) or spacesuits. Once a test subject has been neutralized, the test begins. The test conductor, usually a member of the user's team, supervises test activity from the control room. The test conductor is in charge until the test is completed, except during any emergency situations when the NASA test director automatically assumes control. Under the test conductor's leadership, preplanned procedures are followed to complete specific test objectives.

At the conclusion of the test, the NASA test director resumes control as the test subjects are depressurized and unsuited and equipment is removed, secured, or stowed. After each simulation, key test personnel participate in a debriefing; this is the primary opportunity for the user to record the test subjects' observations which often result in changes to the hardware design. For example, as the EASE/ACCESS test progressed, the design of the structures, such as the size of the struts and beams, was influenced by ease of handling during NBS tests. The debriefing also provides a forum for identifying any facility, pressure suit, hardware, or procedural problems to be corrected before the next simulation.

The NBS staff worked closely with the EASE/ACCESS investigators to conduct several series of neutral buoyancy simulations which started with the development of experiment concepts and continued through personnel training. The neutral buoyancy tests conducted for both the EASE and ACCESS experiments are excellent examples for others considering NBS simulations to support space construction projects.

EARLY NBS LARGE SPACE STRUCTURE RESEARCH

Five years before the mission, researchers from the Massachusetts Institute of Technology (MIT) began early concept studies of large space structures. MIT graduate and undergraduate students were trained to work as test subjects in the Neutral Buoyancy Simulator, and development tests were conducted using a number of test subjects, both suited and unsuited. For early tests, the students used the Apollo A7LB series spacesuits to explore spacesuit capabilities and limitations for assembly tasks.

Preliminary space structure designs were investigated in a series of tests which took place during MIT school breaks. During the first tests conducted in 1980, MIT studied how rapidly people learned and how productive they were in assembling structures underwater. For these experiments, a tetrahedron almost identical to EASE and a truss structure were assembled repeatedly. The students found that their performance was better than expected and test subjects could assemble structures while floating unrestrained. This influenced the concept for the EASE flight experiment.

In 1981, MIT used a series of tests in the MSFC/NBS to build structures with different configurations that filled the water tank and to integrate other hardware with the structures. Figure 1 shows MIT students building a large space structure in the MSFC/NBS.

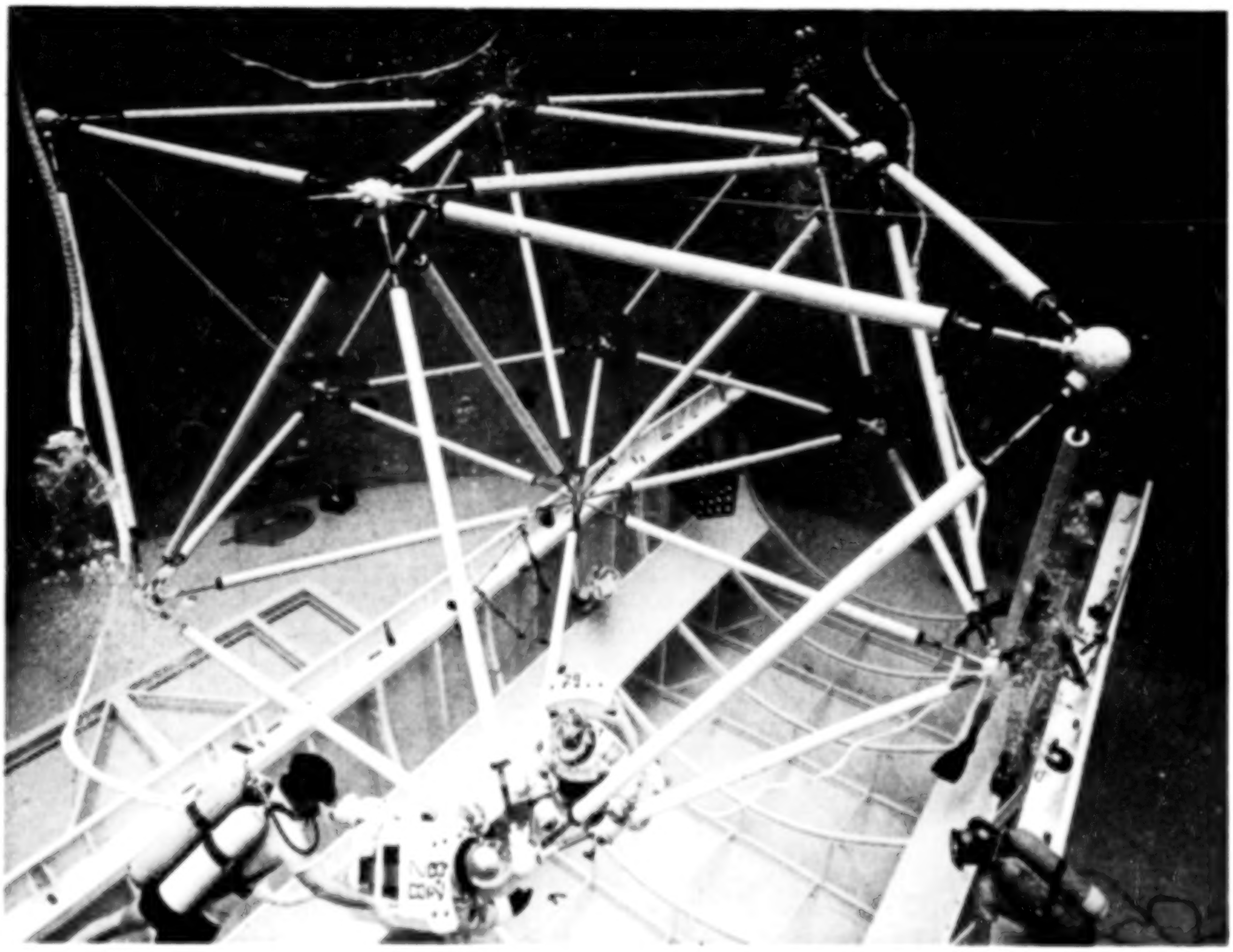

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FIGURE 1

In 1982, additional tests were conducted to examine how the different sizes and shapes of beams and other structural members affected human performance. These tests confirmed that the diameter of the EASE beams could be handled by a suited astronaut underwater and, therefore, could probably be handled in weightlessness. Also, various assembly aids such as a mobile work station similar to the Manipulator Foot Restraint (MFR) work station and the harpoon used to help restrain the large EASE beams were tested. The MIT team also participated in tests for another MSFC project, the Solar Array Flight Experiment (SAFE), a 30.9 meter (100 foot) high solar array which was flown and deployed on Shuttle mission 41-D. Through these tests they learned how to design large space structures for stowage and prepare hardware for flight.

During the same time frame, the ACCESS investigators from the NASA Langley Research Center in Hampton, Virginia conducted a series of neutral buoyancy tests. Langley researchers received suit familiarization training and served as suited test subjects in a variety of NBS large space structure experiments. They assembled various structures using different techniques with subjects restrained, unrestrained, and working from mobile platforms. While some of the structural members were as long as 5.5 meters (18 feet), one structure was composed of struts and nodes similar to those used for ACCESS.

These neutral buoyancy tests led Langley investigators to conclude that the short 23-centimeter (9-inch) struts were easy to handle. The investigators also concluded that the NBS tests showed subjects wasted time moving between work sites. Therefore, by using a technique where the subjects remained at fixed work stations, the Langley investigators decided that they could measure human productivity in assembling large space structures without confounding assembly times with time required for moving building materials to and from the work sites. These tests influenced the decision to use an assembly technique with the astronaut remaining stationary in fixed foot restraints as the ACCESS truss tower was assembled bay by bay and moved up along an assembly fixture.

DEVELOPING THE EASE/ACCESS EXPERIMENTS

Neutral buoyancy tests were a vital part of the EASE/ACCESS experiments. Since EASE and ACCESS were the first large space structures assembled in orbit as a part of a carefully controlled experiment, one of the main goals was to measure the ability of humans to assemble large structures in space. One way to measure this performance was to compare the times required for underwater assembly with the times required for on-orbit assembly. Therefore, investigators carefully recorded the NBS task times for repetitious correlation with on-orbit times.

Both the EASE and ACCESS flight hardware was designed to be as similar as possible to the neutral buoyancy hardware so that accurate correlations between flight and underwater neutral buoyancy assemblies could be made. As is usually the case, the final hardware design for both experiments was refined during neutral buoyancy simulations.

In June 1984 during separate tests, mockups of EASE and ACCESS were mounted on a mockup of the Mission Peculiar Equipment Support Structure (MPESS), a lightweight carrier that bridges the Shuttle payload bay, for the first time and placed in the water tank. During these tests EASE experimenters verified interfaces with the carrier and made decisions about where to mount the beams on the MPESS and where to locate foot restraints for ease of assembly. The EASE assembly technique was also modified so that two people were used to build the structure; one person had done the assemblies during early NBS tests. As a result of these tests, EASE investigators collected the data needed to begin final hardware design of beam latches and other intricate interfaces. Figure 2 shows the EASE payload development tests in the MSFC/NBS.

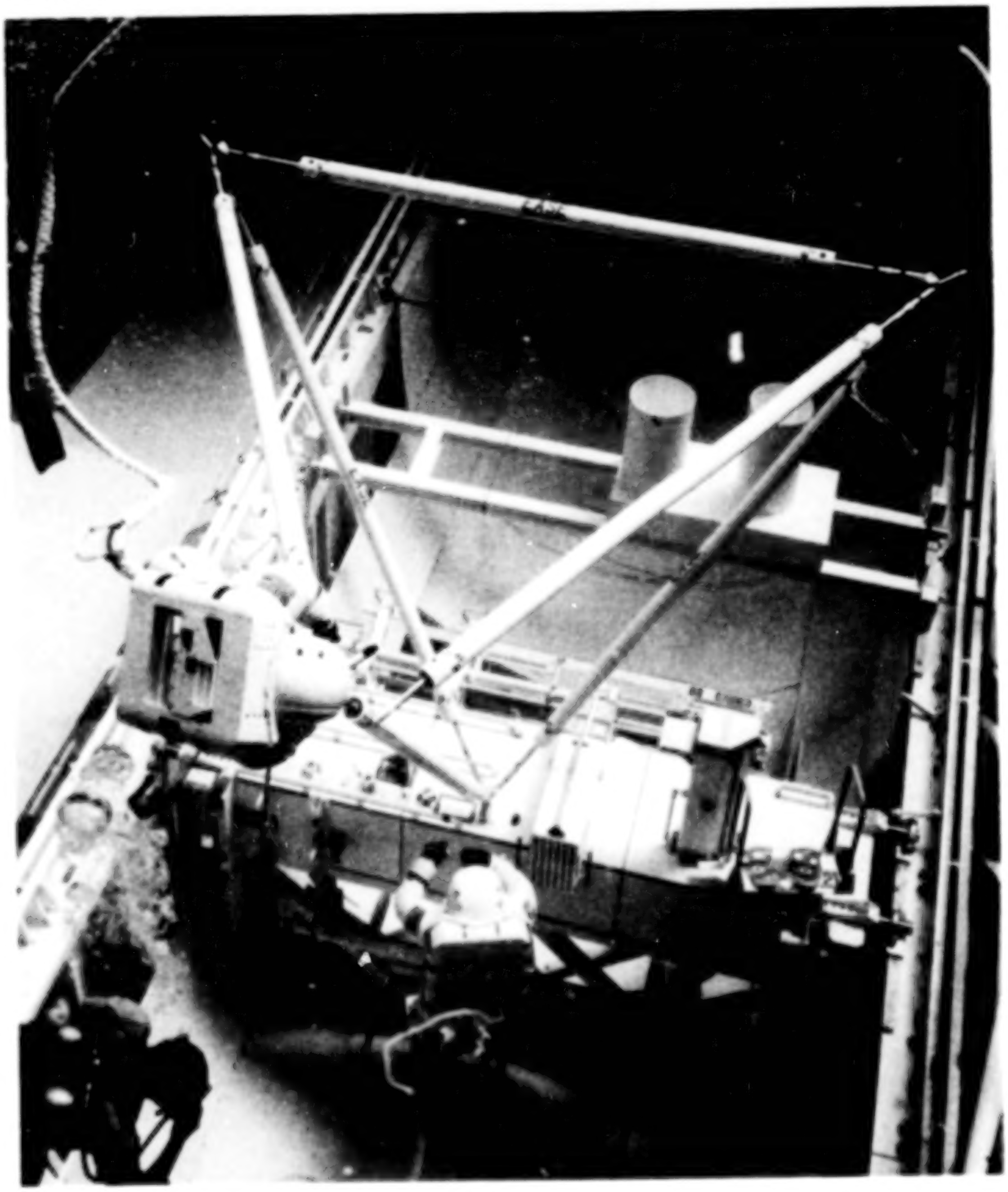

FIGURE 2

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ACCESS investigators also made some hardware modifications, such as changing the latches on the strut and node canisters and modifying some procedures. For example, investigators had planned to tether every strut and node. Neutral buoyancy tests proved that this would quickly fatigue the hands of the suited astronaut. Since the ACCESS components were small, it was decided that they could be handled safely without tethers, and investigators received approval not to tether the ACCESS components. Figure 3 shows ACCESS being assembled in the MSFC/NBS.

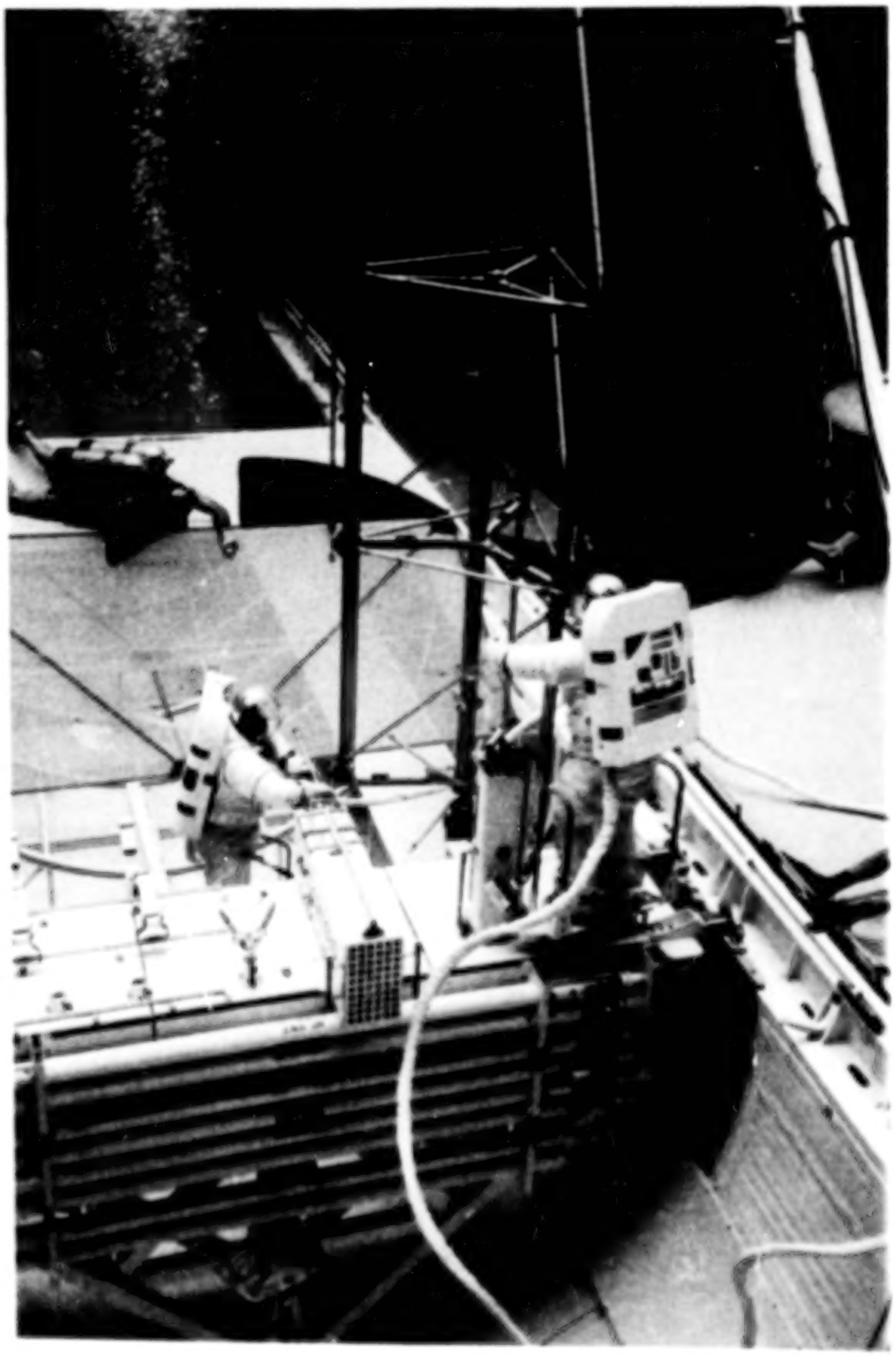

FIGURE 3

From the fall of 1984 until the spring of 1985, MIT and Langley research teams worked together in an unique joint test series. The MSFC/NBS staff prepared the facility for these tests and worked with researchers to complete them. Special underwater cameras were purchased and optics were modified in order to simulate the Shuttle payload bay flight video cameras. It was important to simulate this aspect of the EASE/ACCESS experiments because the cameras had to be placed in the appropriate positions to record construction activities; the cameras were the main data collection devices.

Astronauts Jerry Ross and Sherwood Spring, the two mission specialists assigned to build the structures in space, participated in procedures development and verification tests in the MSFC Neutral Buoyancy Simulator. Design changes continually surfaced, even in the last set of tests a few months before the mission. As a result of the last test series, foot restraints were modified to accommodate the crew. It was critical that the suited astronauts be able to reach specific areas of the structures from the fixed foot restraint work stations.

Contingency procedures and devices were also verified in the NBS. For example, the astronauts practiced contingency procedures for jettisoning the structures in space should the assembled structures get stuck and prevent the payload bay doors from closing. These simulations went smoothly and helped verify that the structures were safe for flight.

Some flight training also was accomplished in the MSFC/NBS because it was the only neutral buoyancy facility equipped with a RMS and deep enough to accommodate the large ACCESS truss tower. The crew trained in the NBS for the detailed test objectives which were planned by the Johnson Space Center to demonstrate the uses of the Space Transportation System as a work platform for space construction activities. The NBS was used to train the astronauts and develop procedures for these tasks: assembling and disassembling EASE and ACCESS from the MFR/RMS; attaching a simulated electrical cable to the ACCESS truss tower; removing and replacing a strut and node from the tower to practice a repair operation; manipulating two connected EASE beams; and manipulating the assembled EASE and ACCESS structures. These tasks were also refined as the astronauts practiced them in the NBS. For example, the crew found that it was easy to maneuver two or three bays of the ACCESS tower; based on this neutral buoyancy test, the task was changed and the entire 10-bay structure was successfully removed and manipulated in flight.

After the hardware and procedures had been refined in the MSFC/NBS, the EASE/ACCESS neutral buoyancy mockups were moved to the Johnson Space Center Weightless Environment Training Facility (WETF) where the astronauts finished training for the mission.

IMPROVING NBS SIMULATIONS

The Neutral Buoyancy Simulator staff not only engages in research and development projects conducted by users of the facility but also supports applied research. New techniques for zero-gravity simulation are being investigated as time permits. Concepts under study include computer data collection and display, robotics, and heads-up displays

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for spacesuit helmets. Over the last few years, new microcomputer equipment has been purchased for the purpose of investigating computerized test instrumentation and data recording.

In these times of budgetary constraints, the NBS is not able to acquire all of desired facility items. The staff uses ingenuity to continue testing with available equipment by reconditioning or modifying equipment not originally intended for underwater use. For example, video cameras have been fitted into special cases so that they can be used underwater to record tests.

The challenge "it cannot be done" invokes the NBS team to prove that "it can be done." An excellent example of this is the underwater Remote Manipulator System, an electrically powered six-degree-of-freedom robot arm. The neutral buoyancy manipulator arm first was developed as a robotics experiment when NASA announced that the Shuttle would be equipped with a manipulator system. At the time, some people said that it would be impossible to develop electronics for the RMS that would operate underwater. However, the NBS staff developed waterproof connectors and a pressurized system to keep water out of the delicate electrical components. Figure 4 shows the underwater RMS being used to practice removing and manipulating part of the ACCESS truss tower.

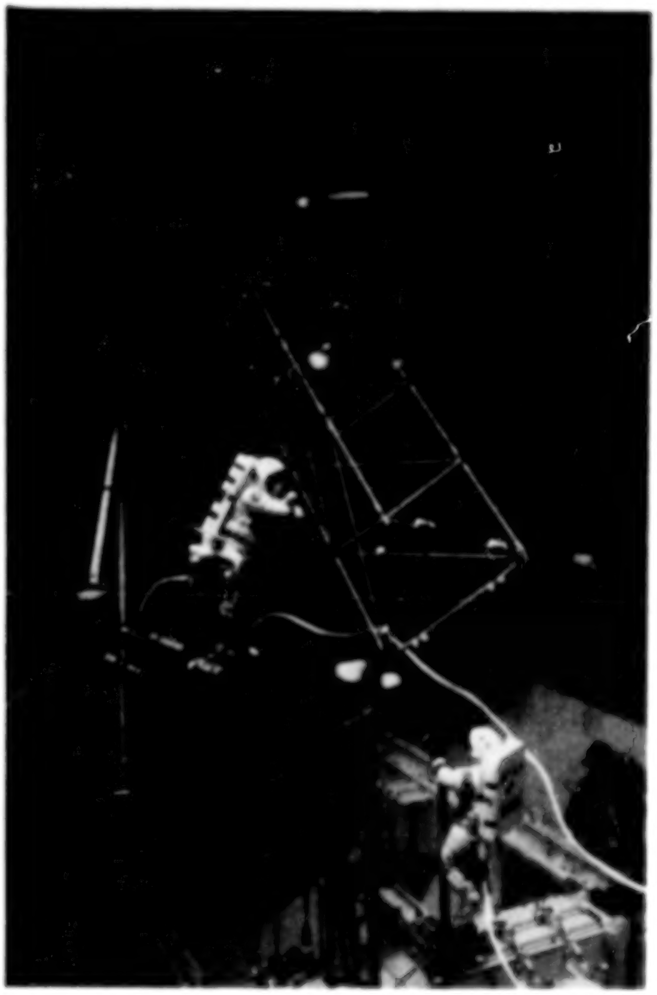

FIGURE 4

The MSFC/NBS manipulator arm is the only one available for neutral buoyancy tests requiring functional simulation of the Shuttle RMS. Presently, the NBS staff is working on techniques to make the underwater RMS operate more like the Shuttle RMS. Recently, toggle switches were replaced with rotational and translational hand controllers to match the Shuttle RMS. Now, the staff is developing a computer program to make the operation of the neutral buoyancy RMS even more similar to the operation of the Shuttle RMS.

The neutral buoyancy RMS was useful during the development of the detailed technical objectives accomplished during the second EVA of the EASE/ACCESS mission. The Marshall Center NBS was the only place were procedures could be developed for activities with one astronaut working on the Manipulator Foot Restraint work station attached to the end of the RMS.

CONCLUSION

The number of neutral buoyancy simulations conducted each year is increasing as NASA's activities in space increase. The goals at the Neutral Buoyancy Simulator are clearly in line with NASA's objectives for aerospace research.

The MSFC/NBS team supports many NASA projects. Current tests are focused on developing concepts for components of the planned Space Station. The success of the EASE/ACCESS mission has proven the value of developing and testing hardware and procedures for assembling large space structures in orbit. The Space Station and other space construction projects can benefit from using the Marshall Space Flight Center Neutral Buoyancy Simulator.

REFERENCE

1. MSFC Neutral Buoyancy Information and Requirements. National Aeronautics and Space Administration/Marshall Space Flight Center. November 1, 1985. (Available as MSFC-RQMT-623)

N88-10879

A SYNOPSIS OF THE EVA TRAINING CONDUCTED ON EASE/ACCESS FOR STS - 61-B

Kathryn A. Havens
Johnson Space Center - DF4

Space Construction Conference
NASA - Langley Research Center
August 6-7, 1986

I. EASE/ACCESS Training Problems

A. Large 3-dimensional structures

- Could not be accomodated in the JSC Weightless Environment Training Facility (WETF) since pool is only 33 feet wide, 78 feet long, and 25 feet deep

- Could be accomplished in the MSFC Neutral Buoyancy Tank (NBT) since pool is 40 feet deep and 75 feet in diameter

B. Training required extensive integration with the Remote Manipulator System (RMS) and Photo/TV plans

- No functional RMS existed at the JSC WETF at that time

- MSFC NBT did have a working RMS although the controls are not "flight-like"

    - Considered negative training for the RMS operator due to work station separation and non-flight-like controls

- The Manipulator Development Facility (MDF) at JSC used a "cardboard crewman" and an MPESS mockup to provide RMS operator training

C. Extensive PHOTO/TV coverage

- Could not provide the requested coverage due to limited locker stowage
- Required a very detailed plan which used a dedicated crewman to accomplish the plan
- Resulted in the most photographically documented EVA to date
- MDF used to provide best visual simulator of the required views for PHOTO/TV training

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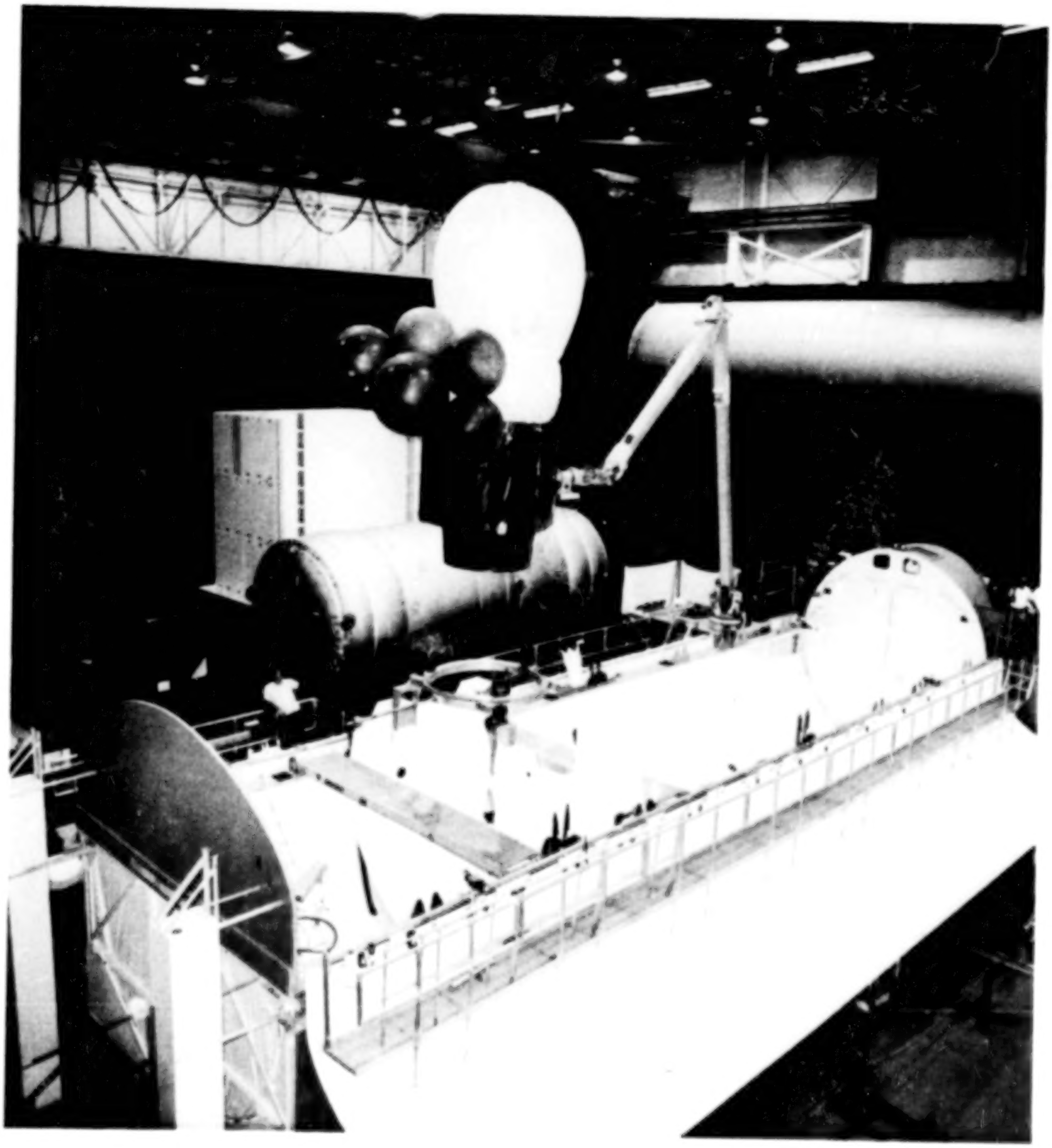

II. Training Plan

A. Normal EVA training plan

- Launch minus 6 to 8 months - Start with classroom or 1-g briefing and SCUBA familiarization of hardware (1 or 2 sessions)

- L-6 to L-3 months (biweekly) - In a tank, perform EMU suited runs of the basic tasks to provide the detailed training and development of procedures

- L-3 months to L-2 weeks (weekly) - Perform end-to-end timeline runs with EMU suited crewmen to build familiarity with timelines and work on contingency plans

NOTE: Anything prior to official assignment of the crew is supported by the EVA representative from the astronaut office

Crewmen who participated in development runs on the EASE/ACCESS hardware include

John Blaha
Gordon Fullerton
Ron McNair
Bryan O'Connor
Ellison Onizuka
Robert Springer
Jerry Ross }
Sherwood Spring } Majority of development work
George Nelson

B. EASE/ACCESS training philosophy

- Early portion of training would be done at MSFC
- The assigned crew cannot be away from JSC during the final 3 months of preparation due to integrated simulations and flying schedules
- Thus the early training would be done at MSFC in August prior to a November launch
- Development of the EVA timeline was difficult because the principal investigators (PI's) had 9 hours of activity to pack into 6 hours of EVA timeline.

C. Actual EASE/ACCESS training

- L-7 months (April 9,10) - Ross, Spring - Early familiarization runs performed at MSFC
  - Hardware already there for continuing development runs
- L-4 months - At MSFC performed end-to-end timeline runs using proposed but too-long timelines
  - Proved to PI's that the amount of activity had to be cut down
  - Reworked the timelines and provided integrated training with the RMS Operator and the crewman in the manipulator foot restraint (MFR)

August 7, 1985 - One run of baseline experiments
- EVA-1 timeline run

August 8, 1985 - One run of contingency procedures due to broken arm system

August 9,12,13 1985 - Three runs of the detailed test objectives or the EVA-2 timeline
- Used a shortened timeline for EVA-2

- L-3 months to L-2 weeks - Training hardware brought to JSC WETF and performed only the baseline experiments or EVA-1 timeline on a biweekly basis
  - Tried to do long runs at ~4.3 psid to closely simulate flight conditions
  - Included 2 EVA simulations, which were integrated with the mission control center
  - Included contingencies for EASE/ACCESS and the EMU

SUMMARY OF TRAINING FOR 61-B EASE/ACCESS

I. EXTRA-VEHICULAR ACTIVITY (EVA) TRAINING

FACILITY	DATE	HOURS	DESCRIPTION
SL NBT	8/7/85	4.0	EVA-1 TIMELINE
SL NBT	8/8/85	3.5	CONTINGENCY RUNS
SL NBT	8/9/85	4.0	EVA-2 TIMELINE
SL NBT	8/12/85	4.0	EVA-2 TIMELINE
SL NBT	8/13/85	4.0	EVA-2 TIMELINE
		19.5	SUBTOTAL
WETF	9/17/85	4.5	EVA-1 & CONTINGENCIES
WETF	9/24/85	5.0	EVA-1 TIMELINE
WETF	10/11/85	4.0	EASE/ACCESS CONTINGENCIES
WETF	10/16/85	4.5	ACCESS DTO, EASE BASELINE
WETF	10/23/85	4.0	EVA INTEGRATED SIMULATION
WETF	10/29/85	4.0	EVA-1 TIMELINE
WETF	11/6/85	4.0	EVA-1 TIMELINE
WETF	11/21/85	5.75	EVA INTEGRATED SIMULATION
		35.75	SUBTOTAL
		55.25	TOTAL

SUMMARY OF TRAINING FOR 61-B EASE/ACCESS - Continued

II. PHOTO/TV TRAINING

FACILITY	DATE	HOURS	DESCRIPTION
CLASSROOM	3/5/85	2.0	
CREW COMPARTMENT	4/8/85	3.0	
FULL FUSELAGE	9/26/85	2.0	
FULL FUSELAGE	10/30/85	2.0	
CLASSROOM	11/20/85	1.5	
		10.5	TOTAL

SUMMARY OF TRAINING FOR 61-B
EASE/ACCESS - Concluded

III. REMOTE MANIPULATOR SYSTEM (RMS) TRAINING			
FACILITY	DATE	HOURS	DESCRIPTION
SES	9/20/85	1.75	
SES	11/6/85	3.00	
		4.75	SUBTOTAL
MDF	8/2/85	3.0	
MDF	9/20/85	1.5	
MDF	9/27/85	4.0	
MDF	10/11/85	2.0	
MDF	10/16/85	2.75	
MDF	10/21/85	1.0	
MDF	10/25/85	3.0	
MDF	10/31/85	2.5	
MDF	11/4/85	2.0	
MDF	11/5/85	2.75	
MDF	11/15/85	4.0	
		28.5	SUBTOTAL
		33.25	TOTAL

D. Results of Training

- Fully defined the timelines for EVA-1 and EVA-2
- Defined the method of using the MFR as a remote work platform
- Resolved safety concerns on jettisoning hardware, strapdowns, and lost pieces
- Completely defined and simulated the intravehicular jobs and integrated these jobs with the EVA crewmen
  - PHOTO/TV documentor
  - Choreographer
  - RMS Operator

INITIAL CONDITIONS (EVA-2)

PET 00:00:00 = MET 04:20:30

✓Airlock stowage complete:
35mm camera (one)

Four wrist tethers
For each crewman:
(1) Wrist tether
(1) Adj wrist tether

IV IMAX STANDBY/SETUP
(PL OPS, IMAX)

IV ✓P/TV06 SETUP (EVA), 1-16
(PHOTO TV, P/TV SCENES)

IV ✓DAP A1,B8 AUTO/VERN
* If PRCS DAP: A6,B8 AUTO/NORM *

RMS POSITIONED FOR GRAPPLE

CRT [SM 94 PDRS CONTROL]
PL ID - ITEM 3 +4 EXEC
BRAKES - OFF (tb-OFF)
MODE - ORB UNL, ENTER
ITEM 24 +4 EXEC
Mnvr to grapple pos

-850, +82, -435, 270, 0, 270

SY	SP	EP	WP	WY	WR
-49	+66	-123	-48	+13	-20

EVA 2 - Summary Timeline

PET	TASK
0 + 00–0 + 15	depress, egress, and translate to MFR stowage
0 + 15–0 + 25	unstow-grapple MFR
0 + 25–0 + 35	configure ACCESS for build
0 + 35–1 + 00	EV1 - low man - nominally build bays 1 - 9
1 + 00–1 + 20	EV1 ingress MFR, install tool boards, load components on boards
1 + 20–1 + 35	EV1 in MFR - build bay 10 from MFR
1 + 35–1 + 55	EV1 in MFR - utility cable installation
1 + 55–2 + 10	EV1 in MFR - ACCESS truss manipulation
2 + 10–2 + 20	EV1 egress MFR, EV2 ingress MFR
2 + 20–2 + 30	EV2 in MFR - disassemble bay 10 from MFR
2 + 30–2 + 35	EV2 in MFR - maintenance/repair task on bay 8
2 + 35–2 + 40	EV2 in MFR - rebuild bay 10
2 + 40–2 + 55	EV2 in MFR - manipulate access truss
2 + 55–3 + 00	EV2 egress MFR
3 + 00–3 + 20	EV2 as low man - Nominally disassemble 10 bays
3 + 20–3 + 30	Stow ACCESS hardware and unstow EASE hardware
3 + 30–3 + 40	Unstow EASE cradle, EV2 ingress MFR
3 + 40–3 + 45	EV2 in MFR - build heat pipe
3 + 45–3 + 50	EV2 in MFR - manipulate heat pipe
3 + 50–4 + 15	EV2 in MFR - build EASE
4 + 15–4 + 30	EV2 in MFR - manipulate EASE
4 + 30–4 + 35	EV2 egress MFR, EV1 ingress MFR
4 + 35–4 + 50	EV1 in MFR - manipulate EASE
4 + 50–5 + 05	EV1 in MFR - disassemble EASE
5 + 05–5 + 10	EV1 in MFR - build heat pipe
5 + 10–5 + 20	EV1 in MFR - manipulate heat pipe
5 + 20–5 + 25	EV1 in MFR - stow heat pipe
5 + 25–5 + 35	Pass tool boards to EV2, EV1 egress MFR
5 + 35–5 + 45	Stow MFR, close EASE cradle
5 + 45–5 + 50	Stow peripheral equipment
5 + 50–6 + 00	Ingress airlock
6 + 00	Repress

FS 8-1 EVA/61-B/FIN

NOMINAL TIMELINE
EVA-2

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III. Flight Data File (FDF) and Flight Rules Production

A. EVA timelines

- Written prior to training at MSFC but rewritten due to length of timelines
- Turned in to editors at L-3 months, which was late - should produce PRELIMINARY version at L-4 months
- Lingering problem of defining timeline with equal amounts of time for both EASE and ACCESS
- Produced the integrated EVA checklist containing detailed EVA, RMS, and PHOTO/TV procedures

INITIAL CONDITIONS (EVA-1)

PET 00:00:00 = MET 02/21:45

✓Airlock stowage complete:
  35mm cameras (two)
  AAPS target with two wrist tethers

IV ✓RMS in viewing position
  ✓P/TV06 SETUP (EVA), 1-16
  (PHOTO TV, P/TV SCENES)

IV IMAX STANDBY/SETUP
  (PL OPS, IMAX)
  ✓DAP A1,B8 AUTO VERN
  *If PRCS: DAP A6/B8 AUTO/NORM *

MNVR RMS TO ACCESS VIEWING POSITION

PARAM sel - JOINT ANGLE
BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER

SINGLE DR to:

	SY	SP	EP	WP	WY	WR
✓	0	+25	-25	+5	0	0
1	+20					
2			-8			
3		+8				
✓	+20	+8	-8	+5	0	0

NOTE
C/W SINGULAR lt - ON (MA) (EP = -7.6)

BRAKES - ON (tb-ON)

EVA-1 Summary Timeline

PET	TASK
0+00-0+30	depress and egress, translate to MPESS
0+30-0+45	configure ACCESS for build
0+45-1+05	EV1 - low man - build bays 1-5
1+05-1+20	EV2 - low man - build bays 6-10
1+20-1+40	EV2 - low man - disassemble bays 10-6
1+40-1+55	EV1 - low man - disassemble bays 5-1
1+55-2+15	stow ACCESS assembly fixture
2+15-2+25	unstow peripheral hardware and unlatch EASE cradle
2+25-2+40	EV1 - low man assemble EASE - 1
2+40-2+55	EV1 - low man disassemble EASE - 1
2+55-3+10	EV1 - low man assemble EASE - 2
3+10-3+25	EV1 - low man disassemble EASE - 2
3+25-3+40	EV1 - low man assemble EASE - 3
3+40-3+55	EV1 - low man disassemble EASE - 3
3+55-4+10	EV1 - low man assemble EASE - 4
4+10-4+25	EV1 - low man disassemble EASE - 4
4+25-4+30	EV2 - low position
4+30-4+45	EV2 - low man assemble EASE - 5
4+45-5+00	EV2 - low man disassemble EASE - 5
5+00-5+15	EV2 - low man assemble EASE - 6
5+15-5+30	EV2 - low man disassemble EASE - 6
5+30-5+40	secure EASE hardware and stow peripheral equipment
5+40-5+45	EV2 - obtain AAPS target and deploy target
5+45-5+55	ingress airlock
5+55	repress

NOMINAL TIMELINE
EVA-1

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INITIAL CONDITIONS (EVA-2)

PET 00:00:00 = MET 04:20:30

✓Airlock stowage complete:
35mm camera (one)

Four wrist tethers
For each crewman:
  (1) Wrist tether
  (1) Adj wrist tether

IV IMAX STANDBY/SETUP
(PL OPS, IMAX)

IV ✓P/TV06 SETUP (EVA), 1-16
(PHOTO TV, P/TV SCENES)

IV ✓DAP A1,B8 AUTO/VERN
* If PRCS DAP: A6,B8 AUTO/NORM *

RMS POSITIONED FOR GRAPPLE

CRT **SM 94 PDRS CONTROL**
PL ID - ITEM 3 +4 EXEC
BRAKES - OFF (tb-OFF)
MODE - ORB UNL, ENTER
ITEM 24 +4 EXEC
Mnvr to grapple pos

-850, +82, -435, 270, 0, 270

SY	SP	EP	WP	WY	WR
-49	+66	-123	-48	+13	-20

EVA-2 - Summary Timeline

PET	TASK
0 + 00-0 + 15	depress, egress, and translate to MFR stowage
0 + 15-0 + 25	unstow/grapple MFR
0 + 25-0 + 35	configure ACCESS for build
0 + 35-1 + 00	EV1 - low man - nominally build bays 1 - 9
1 + 00-1 + 20	EV1 ingress MFR, install tool boards, load components on boards
1 + 20-1 + 35	EV1 in MFR - build bay 10 from MFR
1 + 35-1 + 55	EV1 in MFR - utility cable installation
1 + 55-2 + 10	EV1 in MFR - ACCESS truss manipulation
2 + 10-2 + 20	EV1 egress MFR, EV2 ingress MFR
2 + 20-2 + 30	EV2 in MFR - disassemble bay 10 from MFR
2 + 30-2 + 35	EV2 in MFR - maintenance/repair task on bay 8
2 + 35-2 + 40	EV2 in MFR - rebuild bay 10
2 + 40-2 + 55	EV2 in MFR - manipulate access truss
2 + 55-3 + 00	EV2 egress MFR
3 + 00-3 + 20	EV2 as low man - Nominally disassemble 10 bays
3 + 20-3 + 30	Stow ACCESS hardware and unstow EASE hardware
3 + 30-3 + 40	Unstow EASE cradle, EV2 ingress MFR
3 + 40-3 + 45	EV2 in MFR - build heat pipe
3 + 45-3 + 50	EV2 in MFR - manipulate heat pipe
3 + 50-4 + 15	EV2 in MFR - build EASE
4 + 15-4 + 30	EV2 in MFR - manipulate EASE
4 + 30-4 + 35	EV2 egress MFR, EV1 ingress MFR
4 + 35-4 + 50	EV1 in MFR - manipulate EASE
4 + 50-5 + 05	EV1 in MFR - disassemble EASE
5 + 05-5 + 10	EV1 in MFR - build heat pipe
5 + 10-5 + 20	EV1 in MFR - manipulate heat pipe
5 + 20-5 + 25	EV1 in MFR - stow heat pipe
5 + 25-5 + 35	Pass tool boards to EV2, EV1 egress MFR
5 + 35-5 + 45	Stow MFR, close EASE cradle
5 + 45-5 + 50	Stow peripheral equipment
5 + 50-6 + 00	Ingress airlock
6 + 00	Repress

NOMINAL TIMELINE
EVA-2

STOW ASSEMBLY FIXTURE 6 (0 + 05)

EV1 1) Slide guide rail bracket up into place. Do not pin
EV1 2) Release positive lock on toggle clamp
EV1 3) Release toggle clamp - rotate handle down
BOTH 4) Stow assembly fixture
EV1 5) Secure locking bracket with yellow pip pin
EV2 6) Secure mast clamps
EV1 7) Close assembly fixture toggle clamp - rotate handle up
EV1 8) Close positive lock on toggle clamp

MNVR RMS TO EASE VIEWING POSITION 7

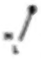
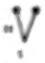
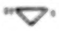
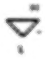
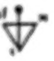
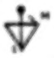
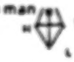
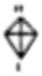
PARAM sel - JOINT ANGLE
BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER

SINGLE DR to:

	SY	SP	EP	WP	WY	WR
1	+20	+8	-8	5	0	0
2		+15				
3			-15			
4	+20	+15	-15	5	0	0

BRAKES - ON (tb-ON)

ASSEMBLE EASE (0 + 15) 8

IV	LOW MAN		HIGH MAN
ΔE - Pan to cluster top,stbd of MPESS	- Harpoon beam with 35' tether and position for cluster installation		
			- Harpoon cluster and attach to beam - Release cluster harpoon
	- Attach beam to aft, port position of base cluster and release harpoon		
	- Harpoon beam with 35' tether and position for cluster installation		
			- Harpoon cluster and attach to beam - Release cluster harpoon
	- Attach beam to aft, stbd position of base cluster and release harpoon		
	- Harpoon beam with 35' tether and pass free end to other crewman		- Translate up aft, stbd beam and receive end of beam
	- Translate up aft, port beam and attach beam to cluster		- Attach beam to cluster
	- Release harpoon		- Translate to aft, port cluster
	- Translate back to base		
	- Harpoon beam with 35' tether		
	- Harpoon cluster, attach to beam, release cluster harpoon		
	- Attach beam to fwd position of base cluster and release harpoon		
	- Harpoon beam with 35' tether and pass to high man		- Harpoon beam
	- Release harpoon		- Attach beam on aft, port cluster
	- Harpoon beam with 35' tether and pass free end to high man		- Translate to aft, stbd cluster and harpoon beam
	- Release harpoon		- Attach beam on aft, stbd cluster - Translate to fwd cluster and attach port, stbd beams

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PET	IV	EV1	EV2
02:00	✓EMU Status	Egress FR #3 and translate to and ingress FR #4	Egress FR #2 and translate to stbd side of MPESS
02:05	ΔE - Release of assembly fixture lock	STOW ASSEMBLY FIXTURE $\boxed{6}$	STOW ASSEMBLY FIXTURE $\boxed{6}$
02:10	ΔA, 16 mm P/TV C/I EVA (EASE) Configure dual 16 mm		
		EASE	
02:15	ΔA,D,E	Translate to PSA (0 + 05) Unstow • MWS • Adjustable wrist tether • 35' safety tether with harpoon attached • Harpoon	Translate to PSA (0 + 05) Unstow • Adjustable wrist tether • Harpoon
02:20	MNVR RMS TO EASE VIEWING POSITION $\boxed{7}$ ΔA,D,E 70 mm Dual 16 mm - ON	Translate to forward MPESS and attach 35' safety tether. Release port EASE beam launch restraint and secure open	Translate to forward, stbd MPESS and release EASE beam launch restraint and secure open Release top 6 beam sleeves from cradle Remove cluster launch restraint pip pins from inboard 3 clusters
02:25	ΔA,D,E *If PRCS: FREE DRIFT*	ASSEMBLE EASE $\boxed{8}$ - (LOW MAN) (Cycle 1)	(HIGH MAN)
02:30			

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CABLE RUN 12

BRAKES - OFF (tb OFF)
MODE - ORB LD, ENTER
Mnvr down to start position
+Z (down) to Z = -805 and
-Y (right) to Y = -120

Adjust attitude to Pitch = 356
Yaw = 285
Roll = 265
with -Yaw (left) to 285
and coordinated
+Pitch (up) and -Roll (left)
to P = 356 and R = 265
Mnvr +Z (down) and +Y (left) to start position

NOTE

Monitor W Y for Singularity at -75
(Alleviate with -Roll (left) crewman face down if needed)
Check clearance from sunshield

-836, -100, -427, 356, 285, 265

SY	SP	EP	WP	WY	WR
+23	+82	-135	57	69	318

(or 8)

BRAKES - ON (tb ON)

When loaded and ready to run cable,

BRAKES - OFF (tb OFF)

Mnvr -Z (up) stopping where required to attach cable

Above Z = -913, use +Roll (right) as required to remain clear of EP singularity at -7.6

To return, reverse process, then

BRAKES - ON (tb-ON)

ACCESS TRUSS MANIPULATION 13

BRAKES - OFF (tb-OFF)
MODE - ORB LD, ENTER
Mnvr to ACCESS removal position:

-858, -93, -790, 0, 290, 0

SY	SP	EP	WP	WY	WR
-16	+121	-105	-43	-48	-186

(or +174)

BRAKES - ON (tb-ON)

Remove ACCESS, then

BRAKES - OFF (tb OFF)
MODE - ORB LD, ENTER
Mnvr -Z(up), -X(aft) and +Y(left) to:

-960, -93, -848, 0, 270, 0

SY	SP	EP	WP	WY	WR
-11	+86	63	84	168	219

(or +141)

BRAKES - ON (tb-ON)

To replace ACCESS, reverse process

PET	IV	EV1	EV2
01:30	CABLE RUN 12		
		CABLE INSTALLATION TASK	
01:35	Pos MFR to top of MPESS	Obtain rope reel from EV2	Pass rope reel to EV1 and tie off lower end on strut
01:40	B → 3/DNLK 16mm - Cable installation and removal 70mm - High EV1	Perform utility cable installation up 10 bays then remove cable and stow (0 + 15)	
01:45			
01:50			
		Pass rope reel to EV2	Temporarily stow rope reel
	E → 3/DNLK		
		ACCESS TRUSS MANIPULATION	
01:55	* If PRCS: FREE DRIFT * ACCESS TRUSS MANIPULATION 13 B → 1 70mm → 3 Bay FOV On EV2 at separation IMAX - scene 6 (Cue Card) 70mm - EV1 with truss	Remove ACCESS truss from assembly fixture	Release ACCESS truss from assembly fixture and push up to remove
		Manipulate ACCESS truss	
02:00			

B. Other FDF products

- Payload Deployment and Retrieval System (PDRS) Checklist containing the detailed RMS procedures - developed at the Shuttle Engineering Simulator (SES) and MDF

- PHOTO/TV Checklist - initial requirements submitted after the training at MSFC but continually revised due to the ongoing MDF training

JSC-16987

Flight Data File
PDRS Operations Checklist

STS 61-B
Flight Supplement

Mission Operations Directorate
Systems Division

Final, Revision A
November 21, 1985

JSC-20687

Flight Data File Photo/TV Checklist

STS 61-B

Mission Operations Directorate
Operations Division

FINAL
November 15, 1985

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

C. Flight Rules

- Effort made to think through all contingencies and plan for them
- Effort to document all agreements
  - PRELIMINARY FLIGHT RULES, published 10/1/85
  - FINAL FLIGHT RULES, published 10/30/85

R RULE

SECTION AB - EXPERIMENTAL ASSEMBLY OF STRUCTURES IN EVA/ASSEMBLY CONCEPT FOR CONSTRUCTION OF ERECTABLE SPACE STRUCTURES (EASE/ACCESS)

CONTENTS

RULE		PAGE
AB-1	ABSOLUTE TIME CUTOFFS	AB-2
AB-2	EVA 2 ORBITER CONSTRAINTS	AB-2
AB-3	LOSS OF EXPERIMENT HARDWARE DURING EVA	AB-2
AB-11	PHOTO/TV FAILURES	AB-4
AB-12	VRCS FAILURES	AB-4
AB-13	EMU FAILURE DURING EVA	AB-4
AB-14	LOSS OF CAUTION AND WARNING DISPLAYS	AB-4
AB-21	EMERGENCY INGRESS	AB-5

IV. Use of the Remote Manipulator System (RMS) and the Manipulator Foot Restraint (MFR)

A. Concern about various failure modes of RMS

- Some failure modes cause the arm to move without command or move in the wrong direction
    - Could overload the structures
    - Could be avoided by procedure - the EVA crewman did not touch the structure until the operator had put the brakes on
    - This procedure also reduced the time when the system was susceptible to failure, ie. only when the MFR was being moved could a failure occur
- Using these procedures the loads were minimized to the brake-slip torque valves

B. Concern about training fidelity for the RMS

- The MSFC NBT arm had limited travel in some joints and too much travel in others
    - Caused procedures to be redeveloped at JSC on high fidelity simulators
    - Ultimately caused some delay in flight procedures

c - 3

N88-10880

RESULTS OF THE ACCESS EXPERIMENT

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Space Construction Conference
NASA Langley Research Center
Hampton, Virginia

August 6 and 7, 1986

INTRODUCTION

The ACCESS (Assembly Concept for Construction of Erectable Space Structure) experiment was conceived in June, 1983 to study manual assembly of a 45-foot long truss structure by two astronauts working in space suits in the Orbiter cargo bay. The experiment was launched 2 1/2 years later, November 26, 1985, on the Orbiter Atlantis, the 23rd voyage of the Shuttle program. From the outset, ACCESS was required to be flown as a payload of opportunity on a Shuttle mission with spare cargo capacity, and returned to Earth in the Shuttle following the experiment. In addition, ACCESS was to be flown with a companion payload of opportunity called EASE (Experimental Assembly of Structures in EVA) which would require sharing of the limited EVA time. Thus, to satisfy these requirements and to maintain manifesting flexibility, ACCESS was designed to be relatively simple to assemble and disassemble, compactly stowed, and lightweight. This paper describes the ACCESS experiment and procedures used by the astronauts, presents photographs of the construction tasks performed in underwater neutral buoyancy training tests as well as on-orbit, and compares on-orbit timelines with data from the neutral buoyancy tests.

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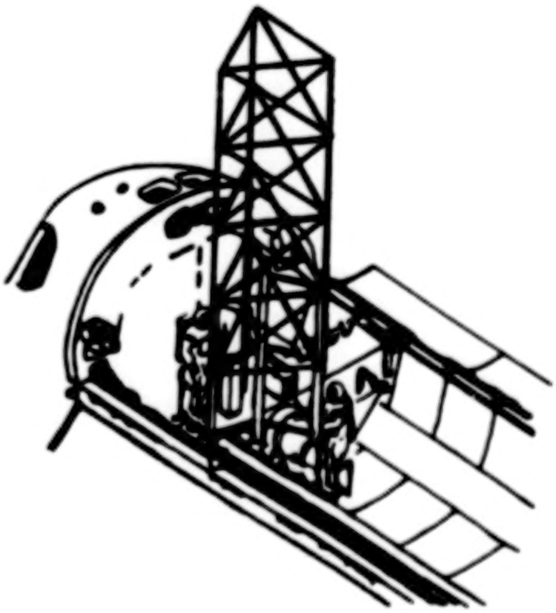
OBJECTIVES AND GENERAL DESCRIPTION

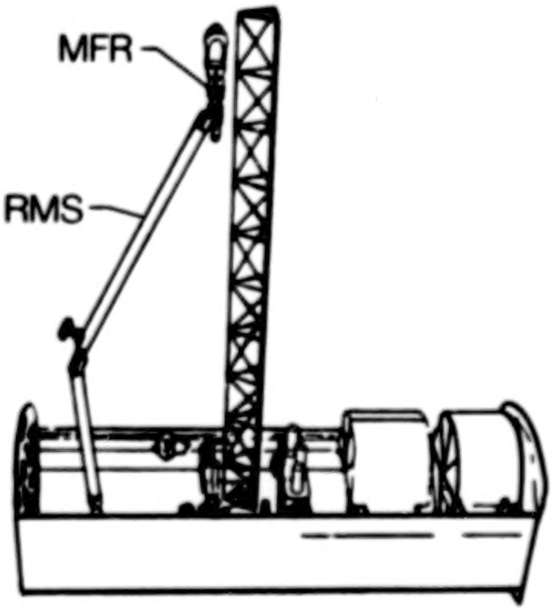
The primary objectives of ACCESS were to: (1) evaluate an assembly line technique for efficient use of astronauts as space construction workers, (2) provide on-orbit data for correlation of assembly rates and techniques developed in neutral buoyancy simulations, (3) gain on-orbit EVA (extravehicular activity) construction experience, and (4) evaluate assembly, handling, and maintenance of a large space structure in support of Space Station development. To meet these objectives ACCESS was divided into two parts, a baseline experiment, and an expanded experiment. As indicated in the figure, the baseline experiment involved two astronauts working from fixed foot-restraints, performing repetitive tasks in an assembly line fashion. The expanded experiment involved one astronaut working from a foot-restraint attached to the end of the Remote Manipulator System (RMS) robot arm to evaluate specific construction and maintenance tasks more suited to a mobile work station approach. These two ACCESS experiments were performed on separate EVA days of the mission. An EVA day is nominally six hours, and had to be shared with the EASE experiment.

EVA-1: Nov. 29, 1985



Baseline experiment
fixed foot-restraints

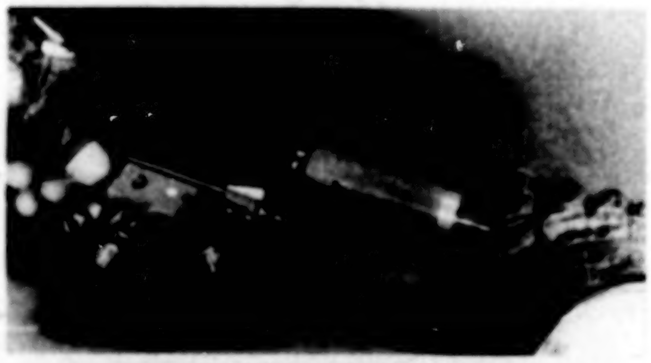
EVA-2: Dec. 1, 1985

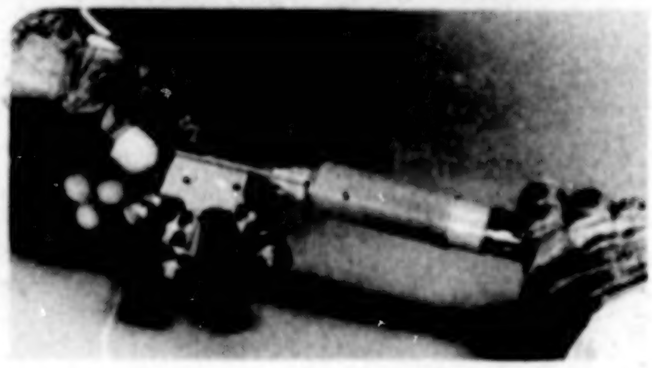


Expanded experiment
mobile foot-restraint

TRUSS HARDWARE

The truss was made up of: (1) 30 longerons (main vertical struts), (2) 30 diagonals (bracing struts), (3) 33 battens (horizontal struts that maintain the triangular cross section of the truss), and (4) 33 nodes (strut connectors). The battens and longerons were 3.95-feet long, the diagonals were 5.81-feet long, and all struts were one inch in diameter. The fully assembled truss consisted of ten identical bays, each with 4.5-foot square sides (measured between node centerlines). Each strut was thermally insulated with a thin gold-colored plastic film (Kapton) for dimensional stability. Each node had six strut attachment points. The joints were designed to permit one-handed engagement. A spring-loaded locking sleeve on the strut end could be placed in an intermediate position so that as the strut and node were mated, the locking sleeve would automatically close to secure the joint. The red-colored node half of the joint was covered by the locking sleeve when the joint was secure, thus giving the astronaut a visual means to verify a proper connection. The locking sleeve could also be locked in a fully open position to permit disassembly of the truss for restowage and return from orbit. None of the ACCESS hardware was tethered for handling on-orbit. All nodes, short struts, and long struts were interchangeable with like parts. All major parts were fabricated from aluminum. A node, batten/longeron strut, and diagonal strut weighed 1.0 lb, 1.55 lb, and 1.94 lb, respectively. The truss weighed 188.8 lb. The moments of inertia of mass about the center of gravity of the truss were $I_{xx} = I_{yy} = 12896$ in-lb-s^2 and $I_{zz} = 352.8$ in-lb-s^2.





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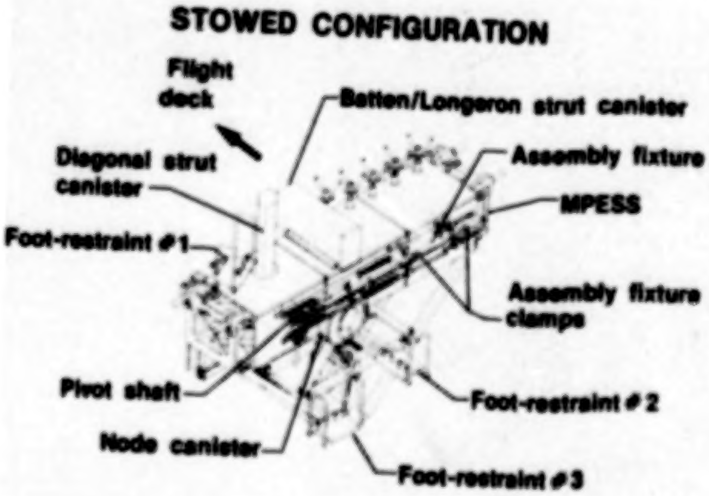
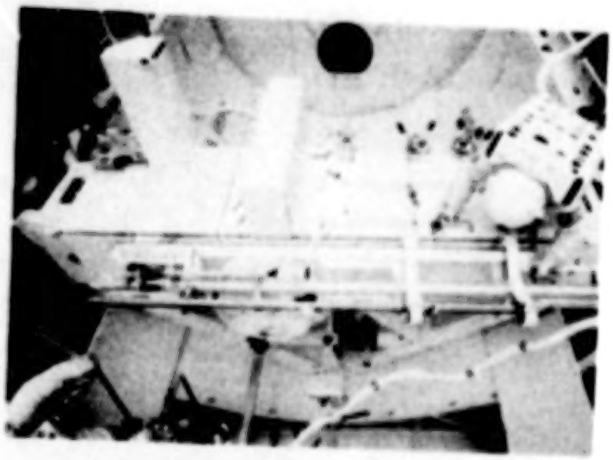
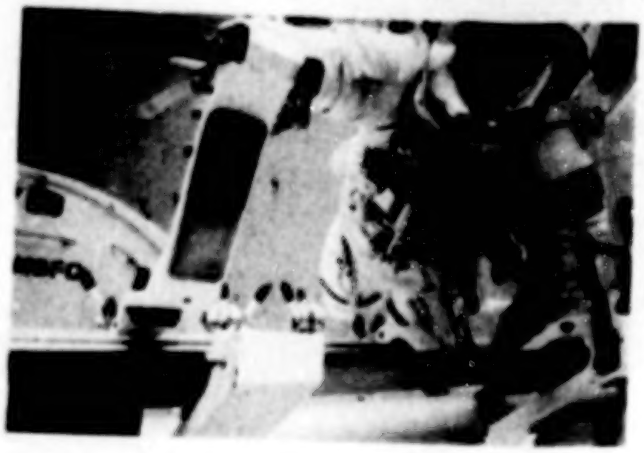
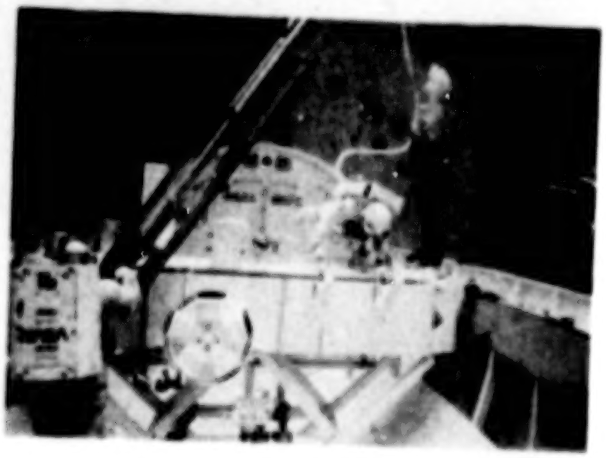
HARDWARE STOWAGE CONFIGURATION

The ACCESS hardware is shown in the figure in its stowed configuration. In addition to the truss hardware, it consisted of three fixed foot-restraints, two strut canisters, a node canister, and an assembly fixture. These components were attached to a pallet called a Mission Peculiar Equipment Support Structure (MPESS), a standard Shuttle pallet which has been used on several other flights. ACCESS was confined to the top left and aft faces of the MPESS. EASE used the rest of the MPESS area. The assembly fixture, which consisted of a central tubular mast with three guide rails (shown folded along the mast), was attached to the aft face of the MPESS by a pivot shaft and two clamps. The pivot shaft was located toward the port side of the MPESS with the shaft axis perpendicular to the aft face. Before assembly of the truss could begin, the astronauts had to release the two clamps, pivot the assembly fixture to an upright position, and deploy the three guide rails. Photographs of some of these activities performed in neutral buoyancy tests are shown in the figure. Foot-restraint three was used only for raising/lowering the assembly fixture. Foot-restraints one and two were used to deploy/fold the guide rails, open/close the strut and node canisters, and assemble/disassemble the truss.



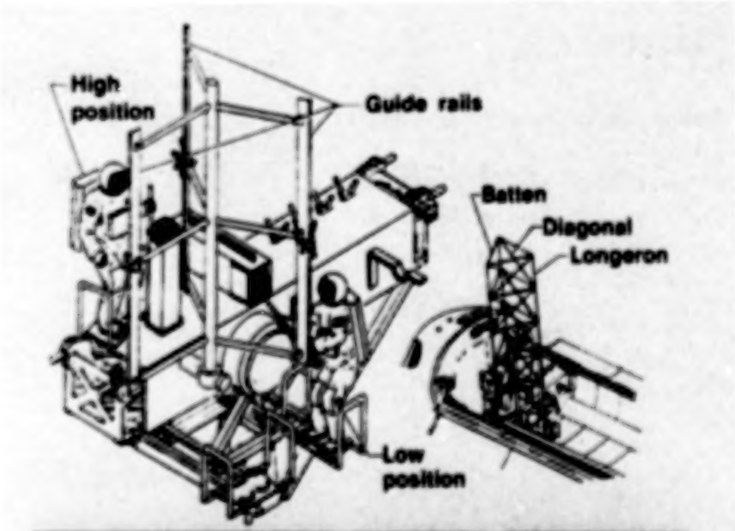






BASELINE EXPERIMENT ASSEMBLY PROCEDURE

The baseline experiment involved an assembly line method of construction which enabled the astronauts to work in foot-restraints at a fixed station. The struts and nodes were made readily accessible so that the astronauts were not required to leave the station during the assembly. The truss was assembled one bay at a time on the lower half of the assembly fixture guide rails which were two bays long. The assembly fixture could be manually rotated about the longitudinal axis of the truss being assembled. Thus, one astronaut, stationed in a "high position" foot-restraint, could make all the joint connections at the top edge of the bay being assembled (approximately 30 % of the work), and the other astronaut, in a "low position" foot-restraint, could install the nodes on the guide rails and make all the connections at the bottom edge of the bay (approximately 70 % of the work). When the bay was complete, the astronauts were required to release a latch and push the bay up the guide rails to the upper half of the assembly fixture where the latch reengaged automatically. The lower half of the assembly fixture was then clear for assembly of the next bay. The process was repeated until the entire 10-bay truss was assembled. The photograph shows the baseline experiment being practiced in the Neutral Buoyancy Simulator at the Marshall Space Flight Center.



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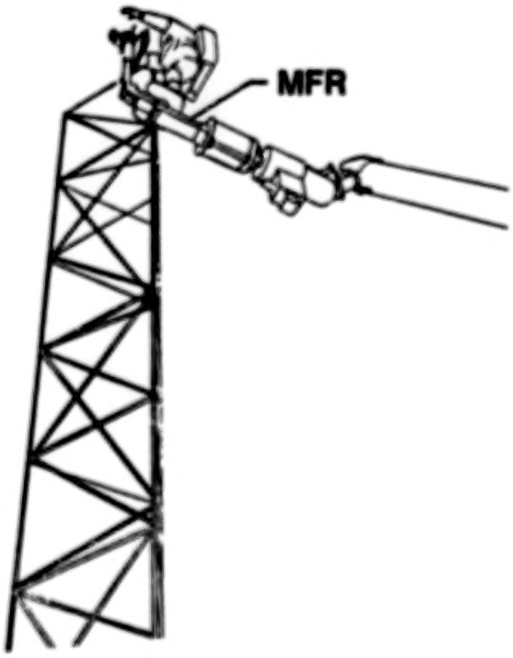
EXPANDED EXPERIMENT TASKS

The expanded experiment used the Shuttle Remote Manipulator System (RMS) and the Manipulator Foot Restraint (MFR) as a mobile work station to assist an astronaut in performing selected construction tasks. The baseline method was used initially to build nine bays of the truss. Then one astronaut ingressed the MFR, loaded nine struts and three nodes onto the MFR Component Carrier, and was moved to the top of the truss to begin the expanded experiment tasks. These tasks included: (1) assembly and disassembly of the topmost bay, (2) installation of simulated electrical cable, (3) replacement of a strut and a node in an interior bay to simulate truss repair, and (4) detachment of the truss from the assembly fixture, manual manipulation of the truss, and reattachment to the assembly fixture. Each astronaut performed some of these tasks. Following the expanded experiment, the astronauts disassembled and stowed the truss and assembly fixture by the baseline method.



Setup
Build 9 bays
(BASELINE)

Assemble 10th bay
Install/remove cable
Manipulate truss
Astronaut #1

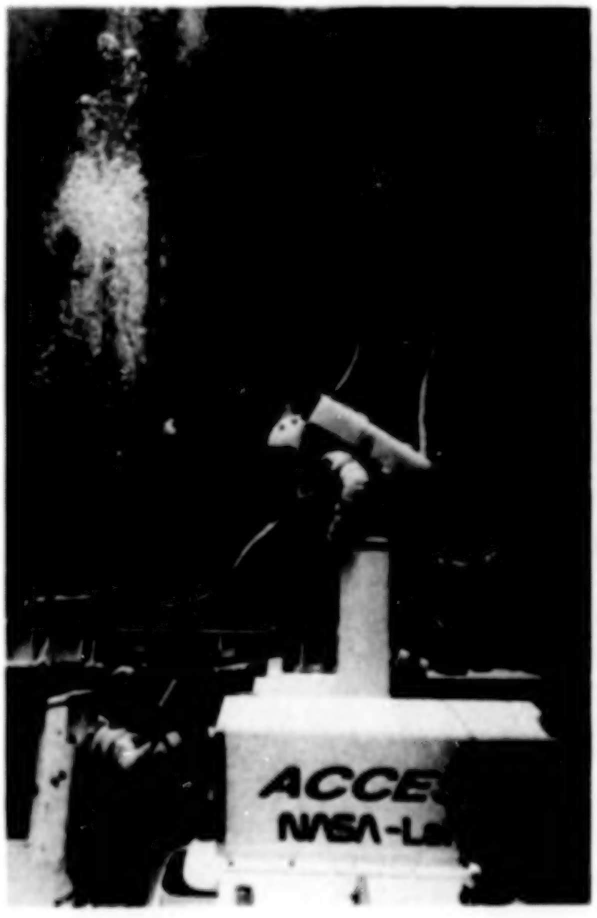
Change MFR astronaut

Disassemble 10th bay
Structural repair
Assemble 10th bay
Manipulate truss
Astronaut #2

Stow & close up (BASELINE)

SAFETY CONSIDERATIONS

Safety considerations heavily influenced the design and fabrication of the hardware. Because ACCESS was a hand intensive experiment (the EVA astronauts were required to handle virtually every piece of the hardware several times), not only did the standard practice of eliminating all sharp edges and snags apply, but glove wear showed up in neutral buoyancy tests and required attention. For this experiment a wear-resistant protective coating (silicone coated Nomex fabric) was designed and substituted for the usual Teflon T-62 cloth used in the palms of the flight gloves of the Shuttle space suit (Extravehicular Mobility Unit (EMU)). In addition, because the ACCESS structure protruded out of the cargo bay, it was necessary to provide redundant means to jettison the hardware in case an emergency situation required immediate closing of the cargo bay doors to return the Shuttle to the reentry configuration. The primary jettison procedure, which involved release of a marman band clamp followed by retraction of a retainer pin, is shown in the figure and could be accomplished in neutral buoyancy in less than 10 seconds. A secondary method involved the removal of four captured bolts and the one inch nut holding the assembly fixture on the pivot shaft. The assembly fixture could then be pulled off the pivot shaft and jettisoned. Both methods were practiced in neutral buoyancy.



Release of assembly fixture

Assembly fixture jettisoned

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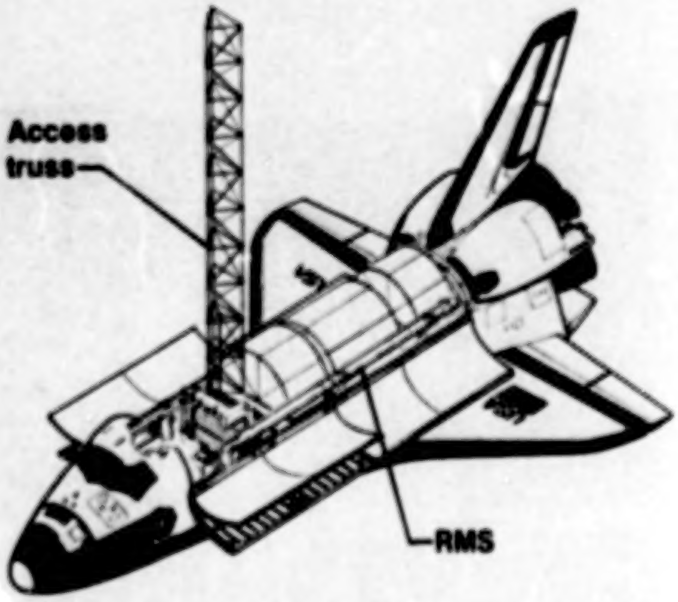
CREW AND CARGO BAY CONFIGURATION

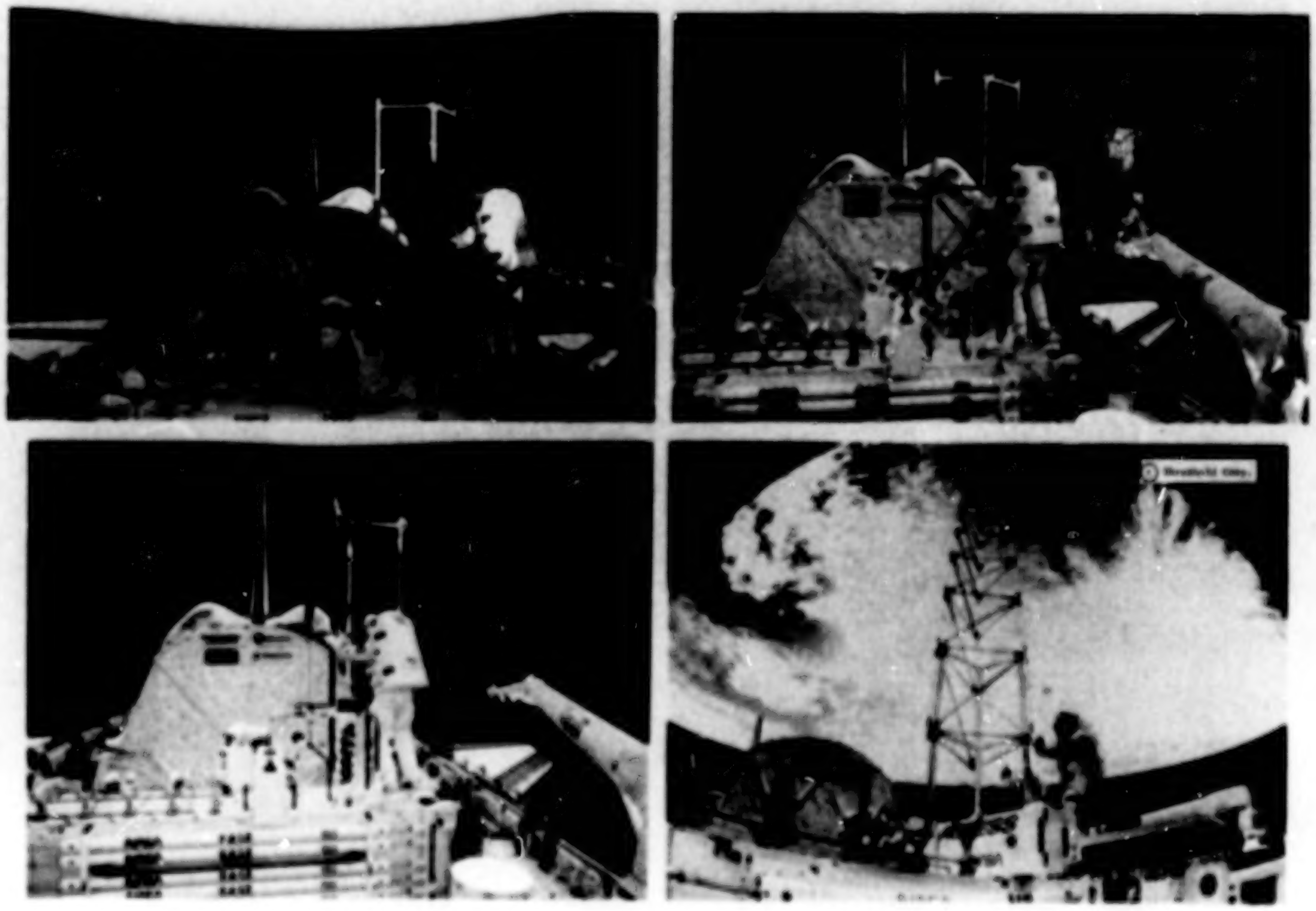
The five crew members responsible for the ACCESS experiment are shown in the photograph. They are Commander Brewster Shaw, Pilot Bryan O'Connor, and Mission Specialists Jerry Ross, Sherwood Spring, and Mary Cleave. In addition to performing their normal Shuttle mission activities, Shaw, O'Connor, and Cleave were responsible for monitoring the highly active EVAs, continuous video and photographic coverage of the experiment tasks, maintaining EVA procedures and timelines, and insuring crew safety. Ross and Spring performed the EVAs; Cleave operated the RMS during the expanded experiment activities. The figure shows the cargo bay configuration and the extreme forward location of the ACCESS payload.

O'Connor, Ross, Cleave, Spring, Shaw



BASELINE EXPERIMENT ASSEMBLY

These photographs show the truss being assembled on-orbit by the baseline method. Top left shows the assembly fixture deployed, the strut canister doors open, and the astronauts in the foot-restraints ready to begin assembly. Top right shows the first bay of the truss assembled and ready to be moved to the upper half of the assembly fixture. Bottom left shows the completed bay in the upper position on the assembly fixture, with construction of the second bay having begun. This photograph was taken while the assembly fixture was being rotated (from left-to-right) following attachment of the bottom end of a longeron and the right end of a batten by the lower astronaut. Following the 120 degree rotation, he will connect the left end of the batten to the node on the next guide rail. The upper astronaut is attaching the top end of the longeron with his left hand during the rotation. Bottom right shows the entire 10-bay truss assembled and moved up the guide rails so that six nodes of the bottom bay attach the truss to the top half of the assembly fixture.



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BASELINE EXPERIMENT TASK TIMES

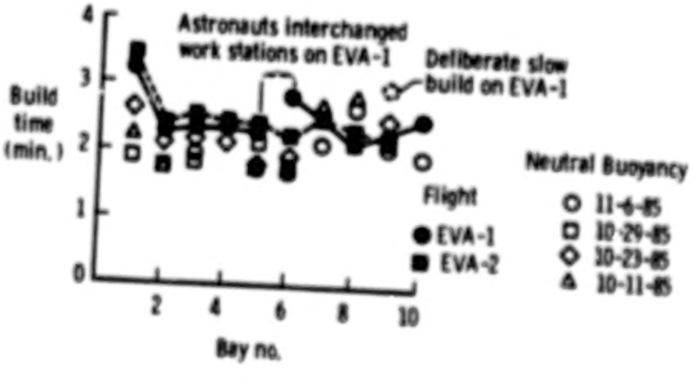
The average task times are given in the Table. The first column of numbers gives average times from tests conducted in the Neutral Buoyancy Simulator (NBS) located at the Marshall Space Flight Center. These tests include some development tests in which the test subjects were not yet fully trained, the assembly procedure not fully developed, nor the hardware finalized. The second column lists the average task times from tests performed by Ross and Spring in the Weightless Environment Training Facility (WETF) located at the Johnson Space Center, after they were fully trained. The final column gives the flight data. The truss was assembled in 25 1/2 minutes on-orbit for an assembly rate of 3.6 struts/min. This was not quite as fast as the astronauts best times in the WETF. However, this result was attributed by both astronauts to having to work with new and, therefore, tighter tolerance hardware on-orbit, whereas the training hardware had become well-worn from the many neutral buoyancy tests. Both astronauts reported that the work effort was about the same as in neutral buoyancy. The plot shows the times taken to build each bay on-orbit (solid symbols) compared with times obtained in neutral buoyancy training (open symbols). The flight data are fairly uniform at about 2.4 min./bay except for the first and sixth bays on EVA-1 and the first bay on EVA-2, which took longer. This phenomenon is probably not a result of learning (both astronauts were already well trained), but more of establishing the "rhythm" of the assembly procedure. Bay six was the first bay constructed on EVA-1 after the astronauts exchanged foot-restraint positions (which also involved exchanging assembly procedures).

Baseline experiment average task times

Task	Time (min.)		
	NBS*	WETF**	FLIGHT
Setup	4.0	3.1	3.5
Assemble 10 bays	30.2	21.7	25.5
Disassemble 10 bays	18.7	35.7	18.9
Stow & close up	5.4	4.5	4.2
	58.3	45.0	52.1

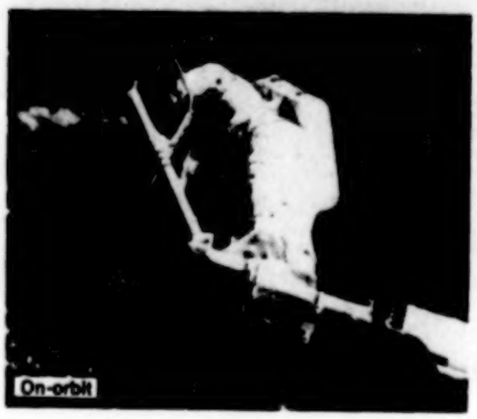
*Includes development tests with untrained test subjects at the Marshall Space Center's Neutral Buoyancy Simulator (NBS).

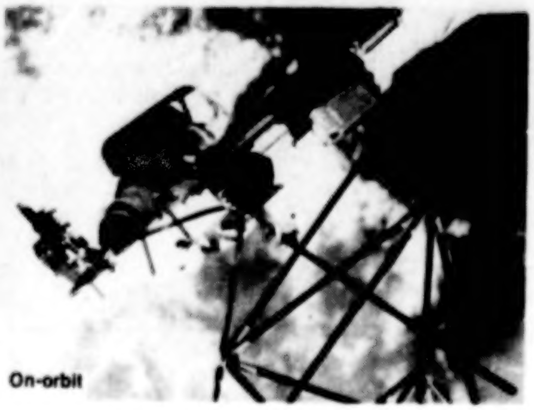
**Highly trained astronaut test subjects Ross and Spring at the Johnson Space Center's Weightless Environment Training Facility (WETF).



EXPANDED EXPERIMENT RMS-MFR ASSEMBLY

The top photographs show the astronaut at the top of the truss and in the process of assembling the top bay both in neutral buoyancy (left) and on-orbit (right). Bottom left shows the astronaut removing a strut from the MFR component carrier on-orbit. This figure also shows how the nodes were stowed on the struts for transport to the top of the truss. Bottom right shows an on-orbit closeup view of the bay assembly. The RMS operator was required to move the astronaut to six different node positions around the truss, and place him close enough to the node to make the structural connections without touching the truss with the RMS. These delicate maneuvers were complicated by the operator's limited view through the aft flight deck windows and having to operate the RMS at the edge of its operational envelope due to the extreme forward location of ACCESS in the cargo bay and its 45-foot length. The moving Earth background complicated the relative motion perception of the RMS operator, and the marginal lighting conditions at the top of the truss further restricted the RMS operator's view during night passes. Increased rates of motion for the RMS were approved for this mission. The maximum rate of rotation was increased from 1.49 deg./s to 2.79 deg./s, and the maximum rate of translation from 0.44 ft./s to 0.77 ft./s.





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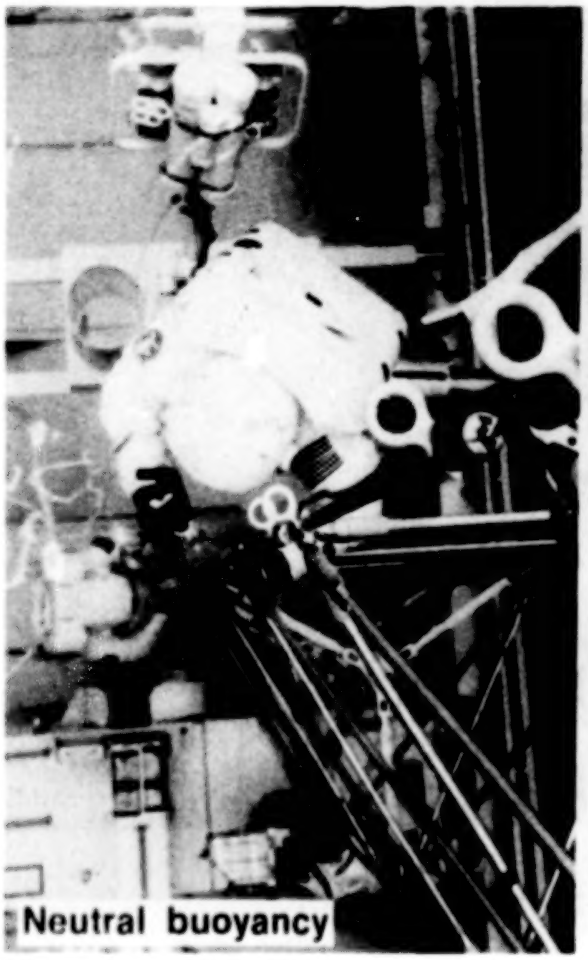
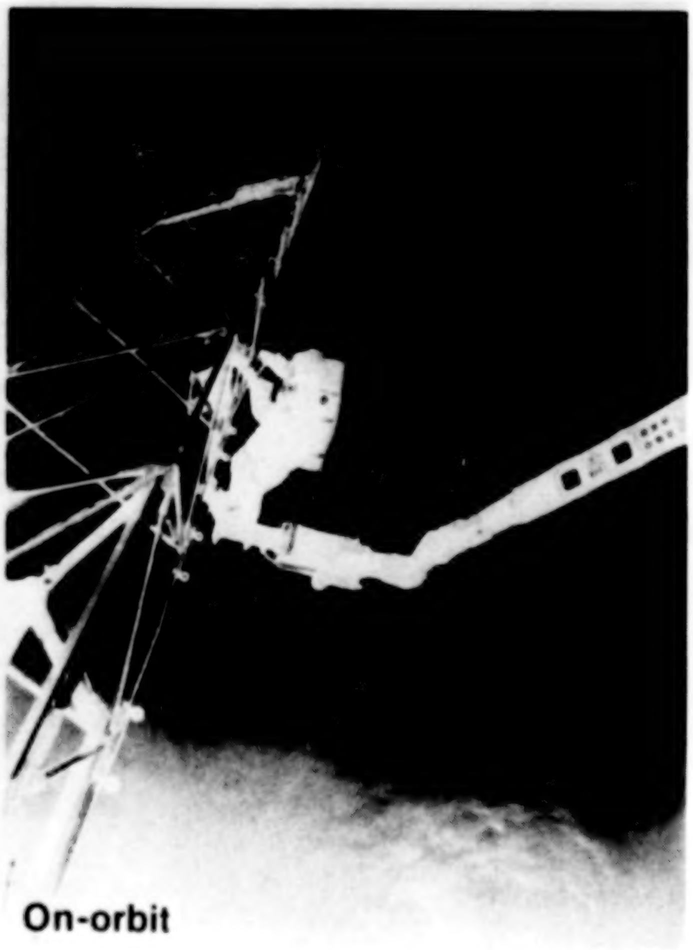
EXPANDED EXPERIMENT CABLE INSTALLATION

These photographs show the simulated cable installation in neutral buoyancy (left) and on-orbit (right). The Shuttle standard rope reel was used for this demonstration. A 5/8-inch diameter rope was unwound from the reel by the astronaut in the MFR and attached to the longeron struts with plastic clips placed on either side of each node. The clips were supplied from a stowage area on the MFR component carrier. Following installation, the rope was removed from the structure, rewound on the rope reel, and the clips were restowed on the MFR. Normal RMS-MFR operations are to move the astronaut into position and apply the RMS brakes before any work on the structure is begun. However, astronaut Cleave reported that during the cable run it became apparent that the cable could be strung without using the brakes.



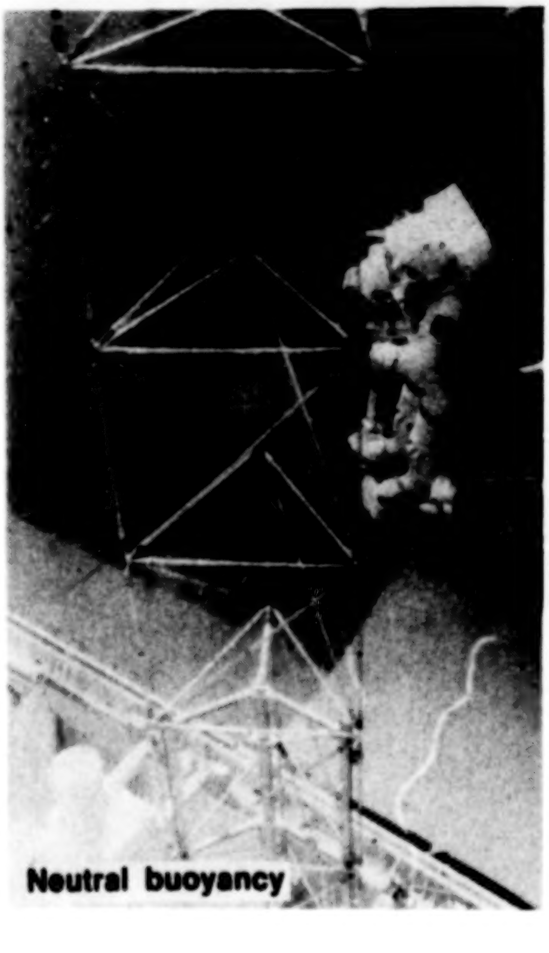
Neutral buoyancy



On-orbit

EXPANDED EXPERIMENT TRUSS REPAIR

These photographs show the truss repair activity in neutral buoyancy (left) and on-orbit (right). In neutral buoyancy, a longeron, diagonal, and node were removed. On-orbit a longeron and node were removed from the seventh bay. (To remove one node, six struts had to be disconnected in this statically determinant truss). The strut and node were then replaced. The truss remained stable in the weightless environment with the struts disconnected and appeared to be unaffected by firings of the Orbiter attitude control system vernier thrusters. (Although likely, it has not yet been determined from the flight records if the vernier thrusters actually fired during this activity. However, the astronauts reported they never noticed vernier firings during either EVA days.)



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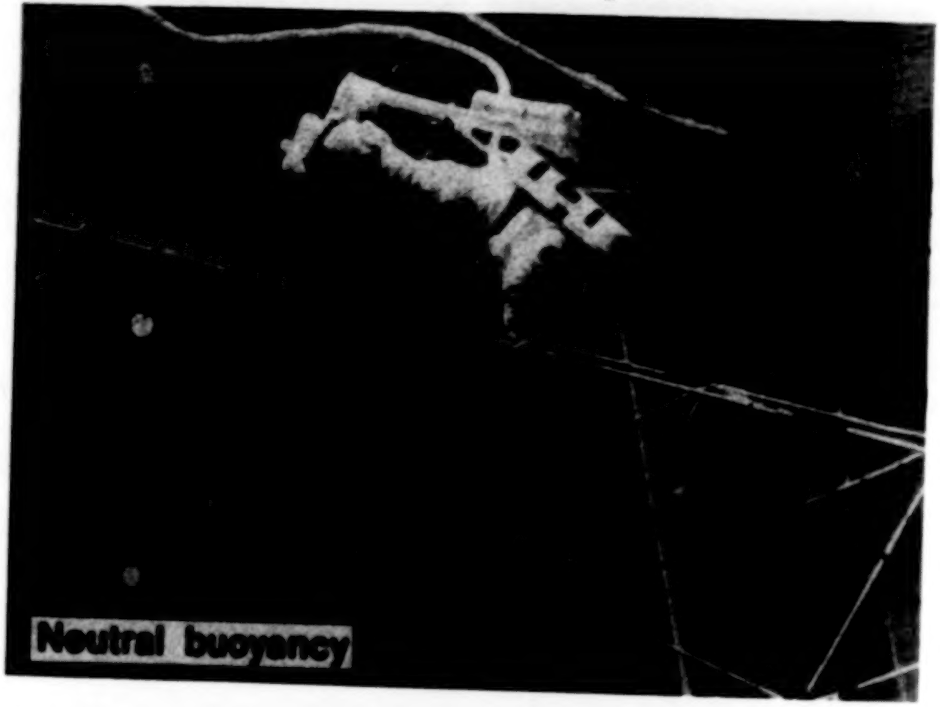
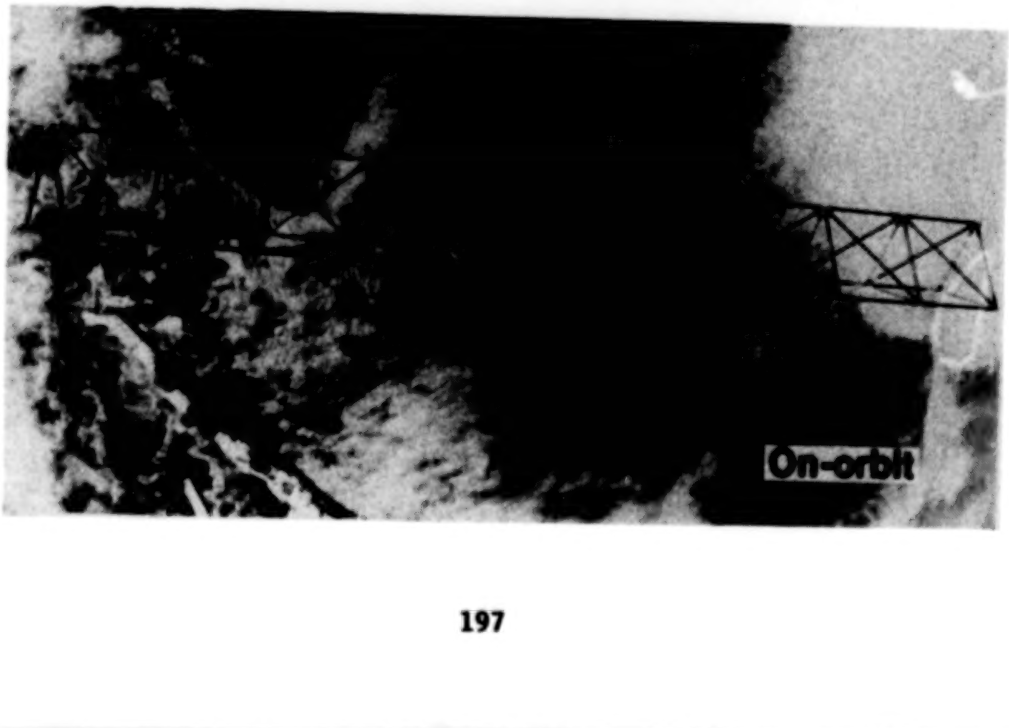
EXPANDED EXPERIMENT TRUSS MANIPULATION

The photographs show the truss being manipulated in neutral buoyancy (top) and on-orbit (bottom). This activity began with the bottom two bays attached to the assembly fixture guide rails. The truss was unlatched from the assembly fixture by the astronaut not in the MFR. It was then slid off the guide rails, rotated, and translated by the astronaut in the MFR. Following the manipulation, it was slid back onto the guide rails until two bays were supported. The truss was maneuvered both from the middle and from the end, and both astronauts reported ACCESS easier to maneuver on-orbit than in neutral buoyancy. Angular accelerations are difficult to determine from the video tapes, but it is estimated that the torque applied to one end of the truss by the astronaut to start or stop the truss rotation was between 25 and 50 foot-pounds. Translational accelerations given the truss along its longitudinal axis probably never required an applied force of more than 10 pounds.





CONCLUDING REMARKS

All basic EVA space construction tasks included in the experiment were accomplished on-orbit successfully, and the construction task times show good correlation with neutral buoyancy data. However, the flight assembly times were slightly longer than the best times obtained in the water tank. This result was attributed by the EVA astronauts to the new, tighter tolerance truss hardware used on-orbit as opposed to the well-worn training hardware used in neutral buoyancy and was, thus, not a space related phenomenon. The baseline experiment demonstrated that erectable structure can be assembled effectively by astronauts in EVA. The average assembly time for the 45-foot truss was 25.5 minutes. The assembly rate was about 3.6 struts per minute. The baseline experiment was judged by the astronauts to be very hand-intensive, especially for the man working in the low position because he had to do about 70% of the work with no periods of rest. Numbness of the fingers occurred which was attributed to pressure points in the gloves. (Gloves are currently being modified and tested in the WETF at JSC using ACCESS training hardware). The work effort level was reported to be essentially the same as that experienced in neutral buoyancy. Over 500 untethered pieces of hardware ranging in weight from one pound nodal joints to the entire 188.8 pound truss were handled without mishap. The astronauts reported that tethering probably would have doubled the assembly time and tripled the hand fatigue. Although the Orbiter was on automatic attitude control during the EVAs, neither astronaut could detect any vernier firings. The truss manipulation was found to be easier than in neutral buoyancy, and both astronauts said a much larger mass could be handled easily if the rates were kept low enough. The increased rates of motion approved for the RMS for this mission were nearly double the rates used on previous flights, and were reported to be comfortable for the astronaut in the manipulator foot restraint, even when the RMS was extended to the top of the 45-foot truss. The success of ACCESS confirmed the feasibility of EVA space assembly of erectable trusses and played a role in the decision to baseline Space Station as a 5-meter erectable structure.

N88-10881

EASE

Experimental Assembly of Structures in EVA

Overview of Selected Results

Presented by

Prof. David L. Akin
Space Systems Laboratory
Massachusetts Institute of Technology

at the

NASA Conference on Space Construction
NASA Langley Research Center

August 7, 1986

EASE Objectives

It should be emphasized at the outset that EASE was never intended to be a structural experiment: the objective of the experiment was to test, in as quantitative a manner as possible, the ability of crewmen to perform in the extravehicular environment. Although this capability has been demonstrated repeatedly on prior EVAs, EASE was intended from the beginning as a measureable activity, with a wealth of data obtained from extensive prior neutral buoyancy experience. The results to be obtained were intended to range across the spectrum of possible disciplines, from the "top-level" results of overall time correlation to detailed reconstruction of body motions and calculation of crew externally-applied forces and moments on the hardware.

EASE Objectives

To investigate and, to the extent possible, quantify the capabilities and limitations of humans in the extravehicular environment

- **Performance**
- **Adaptation**
- **Physical workload**
- **Dynamics**
- **Timelines**
- **Simulation media**
- **Task aids**

EASE Experimental Protocol – 1

This chart, and the following one, reconstruct the experimental development decision path for the MIT Space Systems Laboratory research program which led to the EASE experiment. There was no reason to explore simulation correlation for those activities in which the simulation media did not have any effect: tasks of this type typically deal primarily with detailed manual and digital dexterity. The choice made was to rather focus on tasks requiring the use of major muscle groups, and significant interaction with the local environment. Structural assembly was chosen as an ideal trial task for these types of motions. The experimental approach was to first model the motions mathematically in both neutral buoyancy and flight environments, validate the model in parabolic flight on the NASA KC-135 aircraft and underwater, then use the model to design and scale the hardware for maximum dynamic correlation between the two environments. This hardware was then used for six years, in the development of an extensive data base on human performance in neutral buoyancy simulation of EVA structural assembly tasks.

EASE Experimental Protocol – 1

- Focus on tasks in which the unique characteristics of the environment are significant
  - → Gross physical motions exercising major muscle groups
- Choose a task which maximizes desired motions and minimizes task-dependent metrics
  - → Structural assembly
- Use simulation media to develop in-depth understanding of the physical principles
  - → Body dynamics models
  - → Dynamically scaled hardware
  - → Six-year neutral buoyancy data base

EASE Experimental Protocol – 2

The mathematical models discussed on the preceeding page required the use of hardware with a large mass and moment of inertia (in comparison to the suited mass of the crewman). However, several procedural questions had to be answered to finish the hardware specifications. It was desired to make the task reasonably challenging for the subjects: for this reason, the connectors were designed with a minimum of allowable angular misalignment (approximately ±1°). While most of the NASA EVA work station designs studied incorporated foot restraints for almost all work sites, it was determined that this would pose an unacceptable burden if made to be a universal requirement, especially for large structures such as extensive space platforms. For this reason, the assembly task was designed to be primarily performed without body restraints, and significant effort placed on means of identifying crew adaptation to the space environment. With the approval of the EASE flight experiment, the prime objective in hardware design was to maintain the same mass and moments of inertia as the neutral buoyancy hardware, to maximize correlation to the existing data base. This, to a great extent, fixed the design of the flight hardware. The required masses precluded flying a large number of components for an extended structure, such as had been assembled in tests at MIT and NASA Marshall. Instead, enough hardware was flown for a simple tetrahedron (with spares), and repetitions obtained by repeated assembly and disassembly of this basic structure. Integration limitations prevented Orbiter electrical or data interfaces with the EASE hardware, and forced the design of a data collection system based on existing visual recording means (video and film cameras).

EASE Experimental Protocol – 2

- Tailor the tasks to stretch the capabilities of the test subjects
  - → Low-tolerance connectors
  - → Lack of restraints
  - → High masses and moments
- Design the flight experiment to validate and correlate the simulation experience
  - Maintain configuration, masses, and moments from neutral buoyancy
- Work within the limitations of the STS system
  - → Fly simple structure and test repetitively
  - → Use visual methods of data collection

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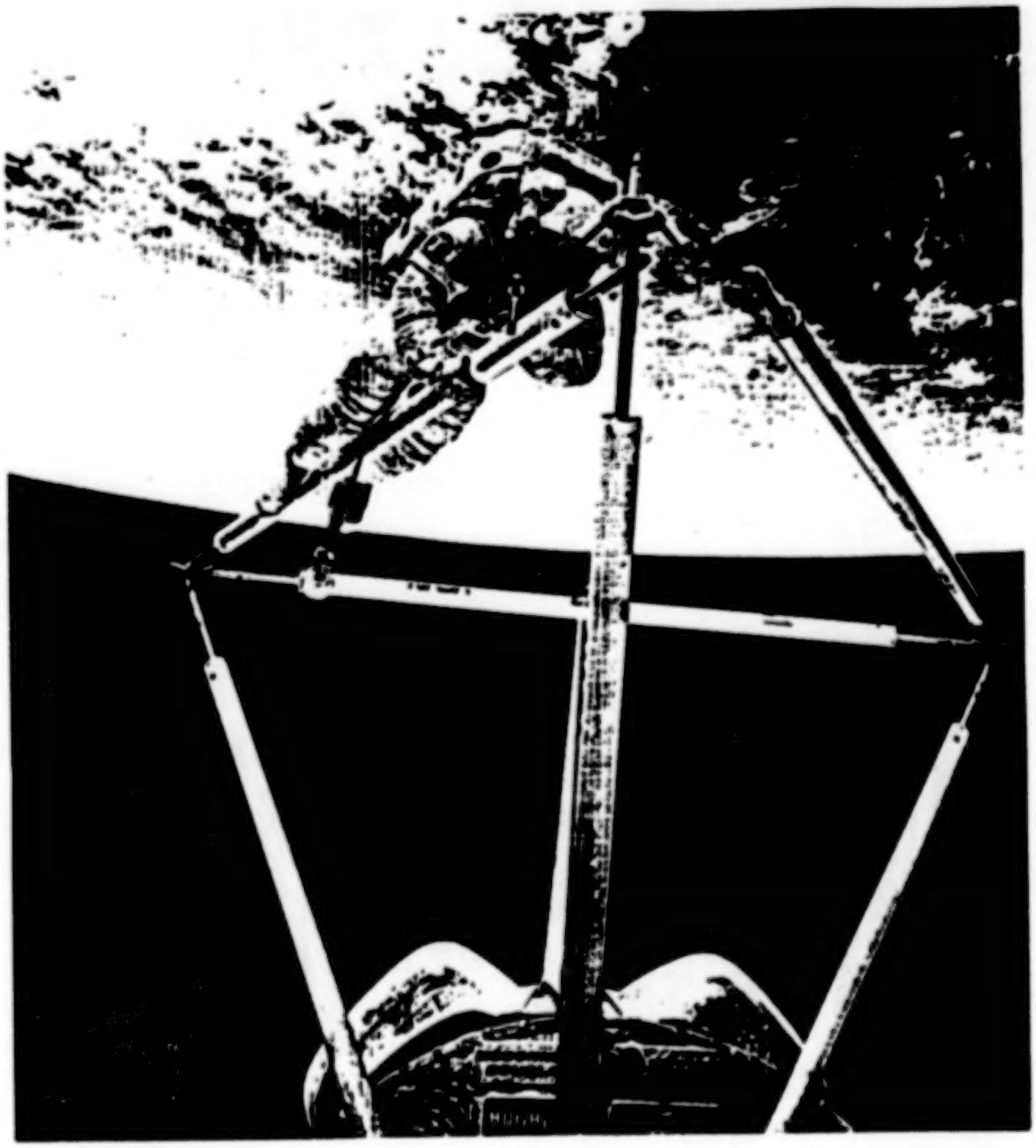
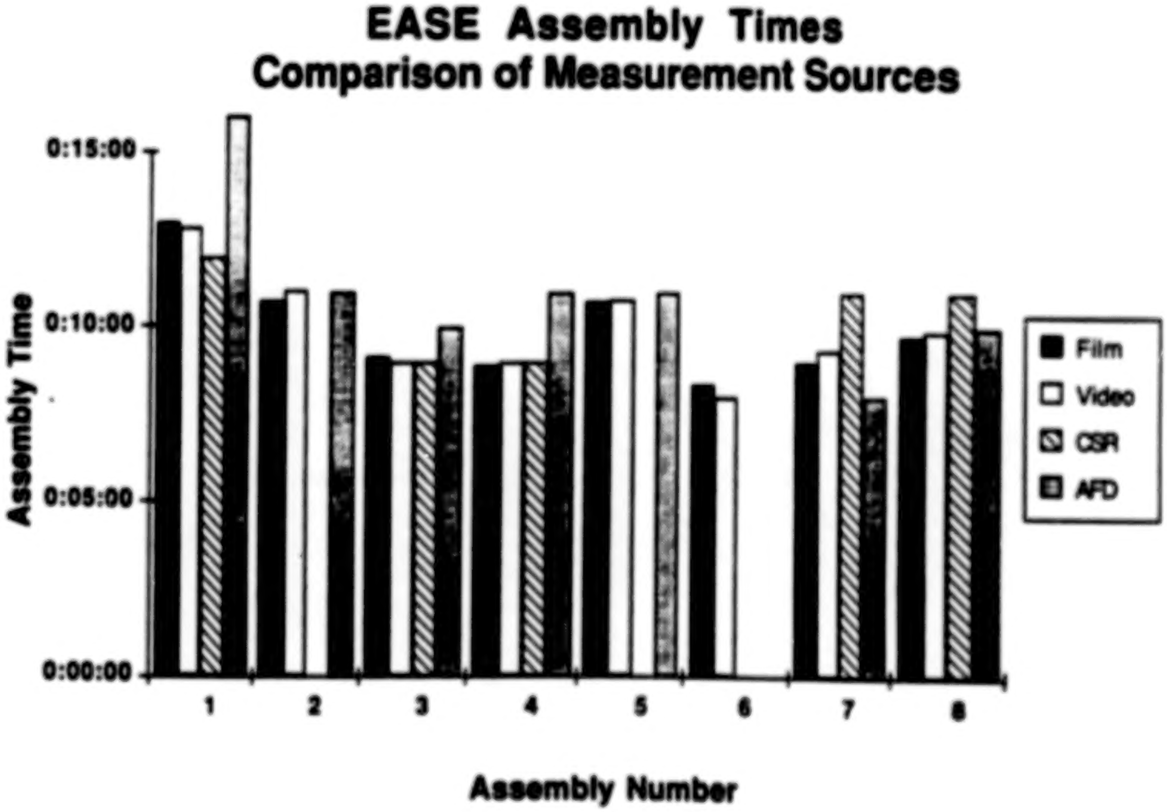
EASE Assembly On-Orbit

This photograph shows the completed EASE tetrahedron on-orbit. Of particular significance is the crewman at the top of the structure (referred to as the "high man"), working without fixed body restraints. The crewman at the base cluster ("low man") did have a foot restraint, to ease access to the base cluster and to hardware restraint fixtures. A completed EASE structure has a mass of 180 kg; the length of an assembled side of the structure is 3.87 m.



EASE Assembly Times
Comparison of Measurement Sources

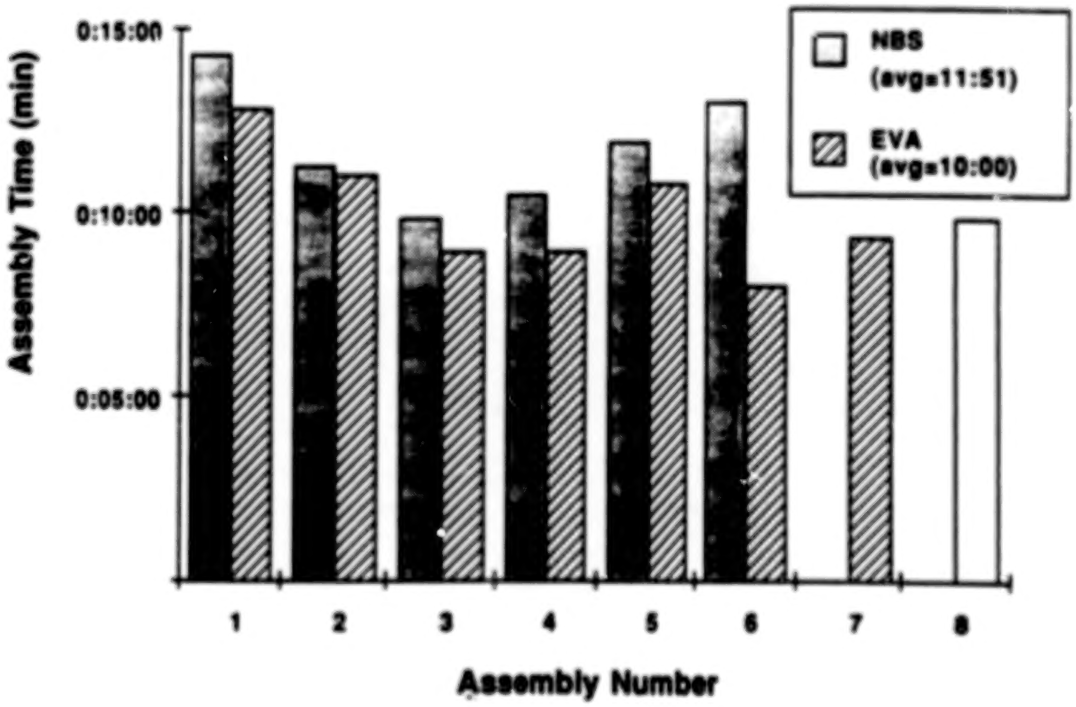
Of the most immediate concern was the correlation of assembly times on-orbit with those of the same crew during pre-flight training. Four means of measuring these flight activity times were available: post-flight times could come from the video images (with superimposed Greenwich Mean Time), and from the stereo 16mm film images (shot at 1/4 normal frame rate). Real-time estimates were made in the Customer Support Room ("CSR") during the mission, but these times were suspect due to lack of communications with the orbiter during significant portions of each orbit. The 61-B mission pilot also timed EASE activities real-time, using his wristwatch: this data source was also suspect, due to his many other duties of more pressing import. Due to the controlled nature of the post-flight timing sources, this data was used for subsequent analyses.



Neutral Buoyancy Simulation – Extravehicular Activity Correlation

This chart compares the assembly time established on-orbit to those demonstrated by the flight crew during an integrated simulation one month prior to flight. This integrated simulation is used as the most directly applicable ground experience to the overall EVA procedure: effects of the simulation (such as malfunctions artifically induced for training purposes) have been factored out of the assembly times shown here. The six assemblies shown for neutral buoyancy represent the planned scope of EASE activities: eight assemblies were actually performed on-orbit. In both cases, the crewmen maintained their positions throughout the first four assembly cycles, then switched places for all subsequent assemblies. As may be seen, the times for each assembly on-orbit were less than that for the corresponding assembly in neutral buoyancy. On the average, the mean assembly time was 18% less in flight than in underwater simulation. The same trends are evident in both cases: decrease in assembly times over the first few runs as the crew gets warmed up and learns their unique tasks; an increase in time for assembly 5, as the crewman change positions and are faced with new tasks; and a gradual lengthening of assembly times as the crew becomed fatigued in the later stages of the experiment.

NBS–EVA Correlation

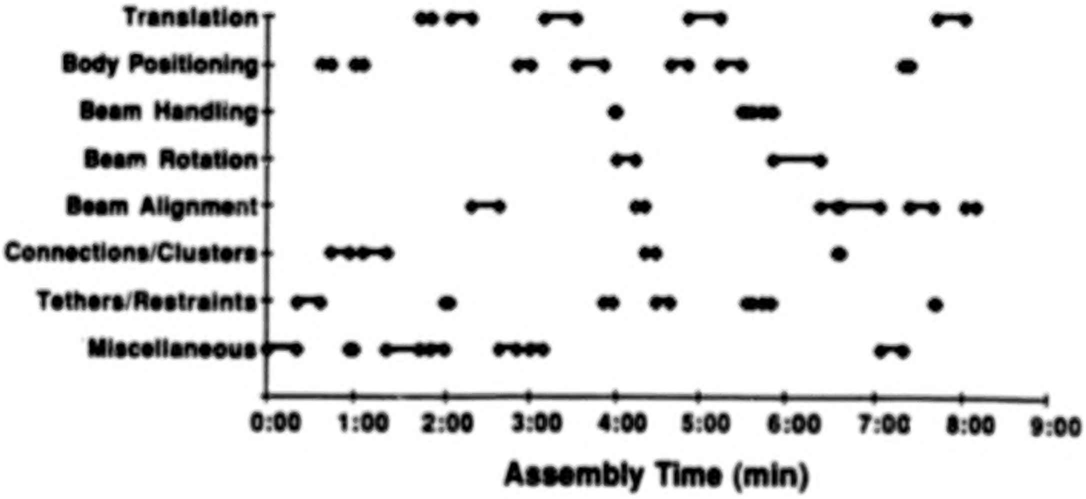


Sample EVA Timeline

All EASE activities were broken down into the eight categories shown on this chart. Each of the video tapes were analyzed post-flight to categorize the activities of the crew throughout the EASE procedures. This is an example of a traditional timeline analysis, which shows the activity of the "high man" (crewman working without fixed restraints at the upper level of the structure) during the third baseline assembly of the EASE structure. This represents the raw form of the data, which is further analyzed in the following charts.

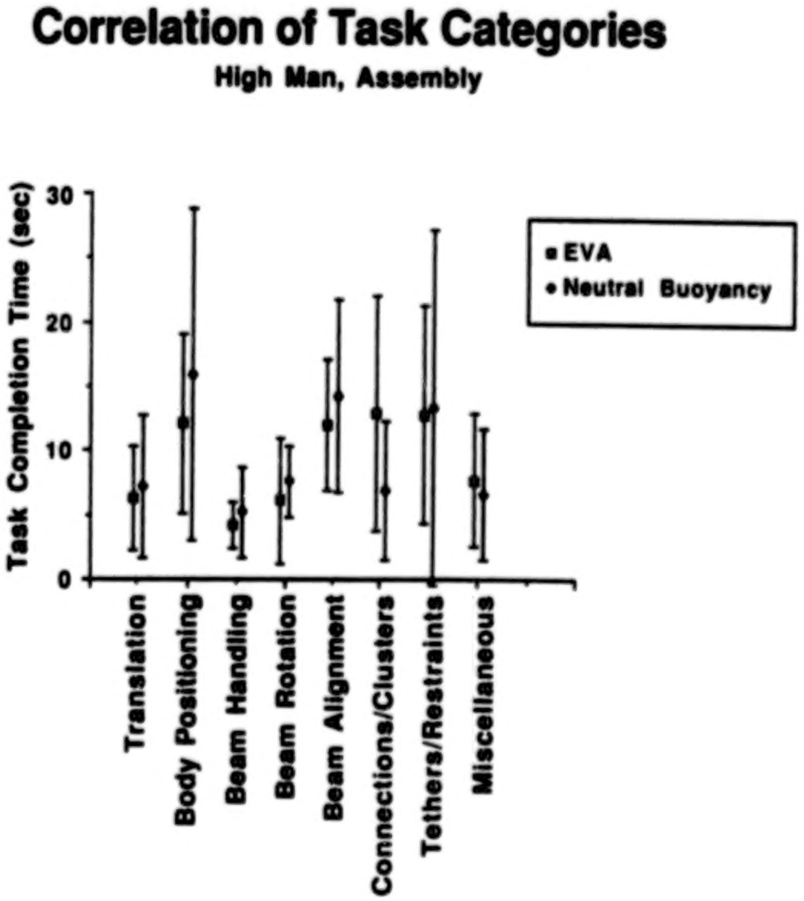
EVA Timeline

Cycle 3 Assembly, High Man



Correlation of Task Categories

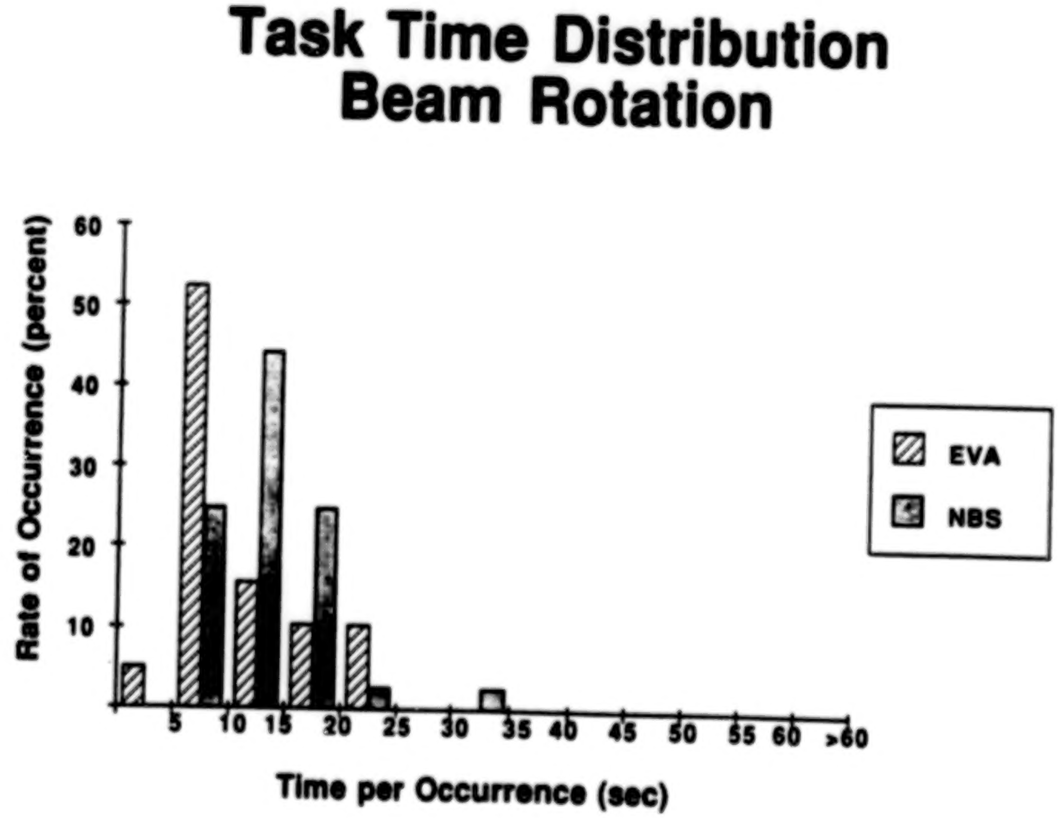
In this example, the data from the "high man" position for all eight of the baseline assemblies was analyzed, along with the corresponding timeline data from underwater simulations prior to flight. The chart displays the mean and standard deviation values for each of the eight task categories. While some minor variances occur in the mean times per task between EVA and neutral buoyancy, the large size of the standard deviations in each case prevent more quantitative conclusions from being drawn from this data. Obviously, some further analysis must take place, incorporating the trends of the distribution of data in each category.



task correlation

Task Time Distribution – Beam Rotation Task

The EASE hardware was designed to emphasize the mechanical activities of assembly, particularly the manipulation of large moments of inertia. For that reason, the two most significant task categories were those of beam rotation (coarse motion of EASE beams from one end) and alignment (fine motion, prior to joint connection). Comparing the beam alignment task in space and underwater, this chart demonstrates that the neutral buoyancy simulation (NBS) case demonstrates greater mean time for rotation. This is due, in large measure, to the effect of water drag in resisting steady motion underwater. It should be noted that, due to the assembly procedures and configuration of the EASE hardware, all beam rotations included in this data base covered a total of 60° from start to finish.



Task Time Distribution
Beam Rotation

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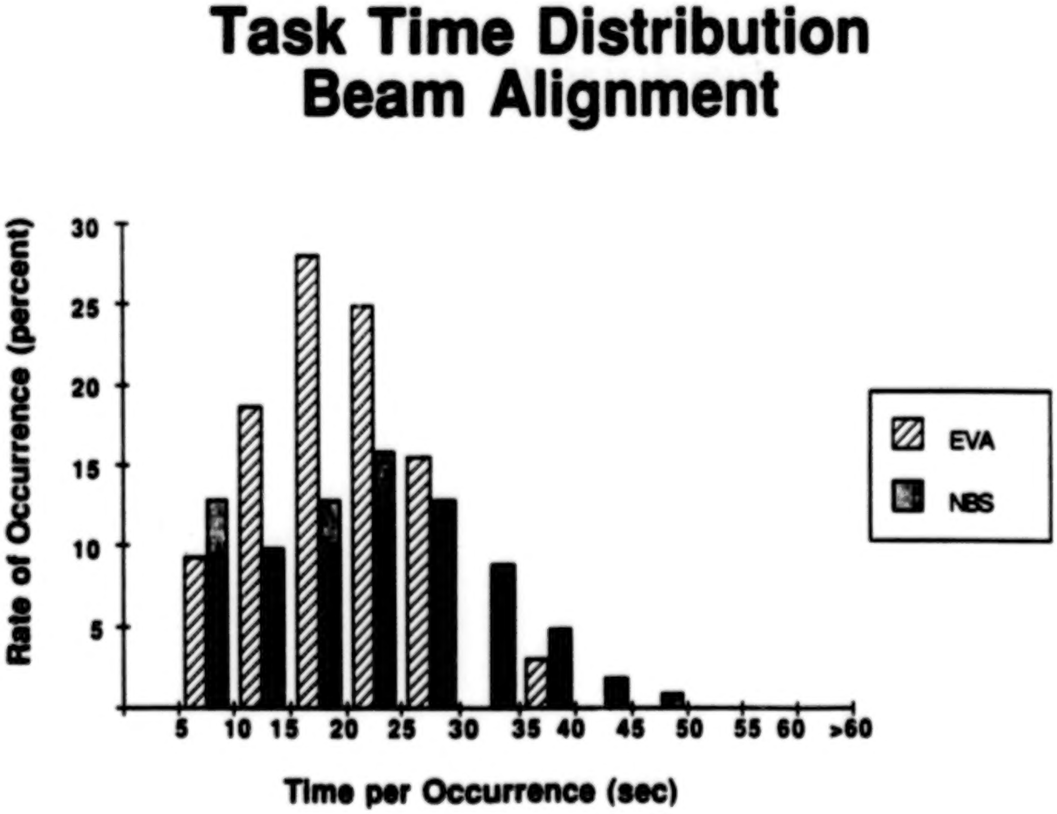
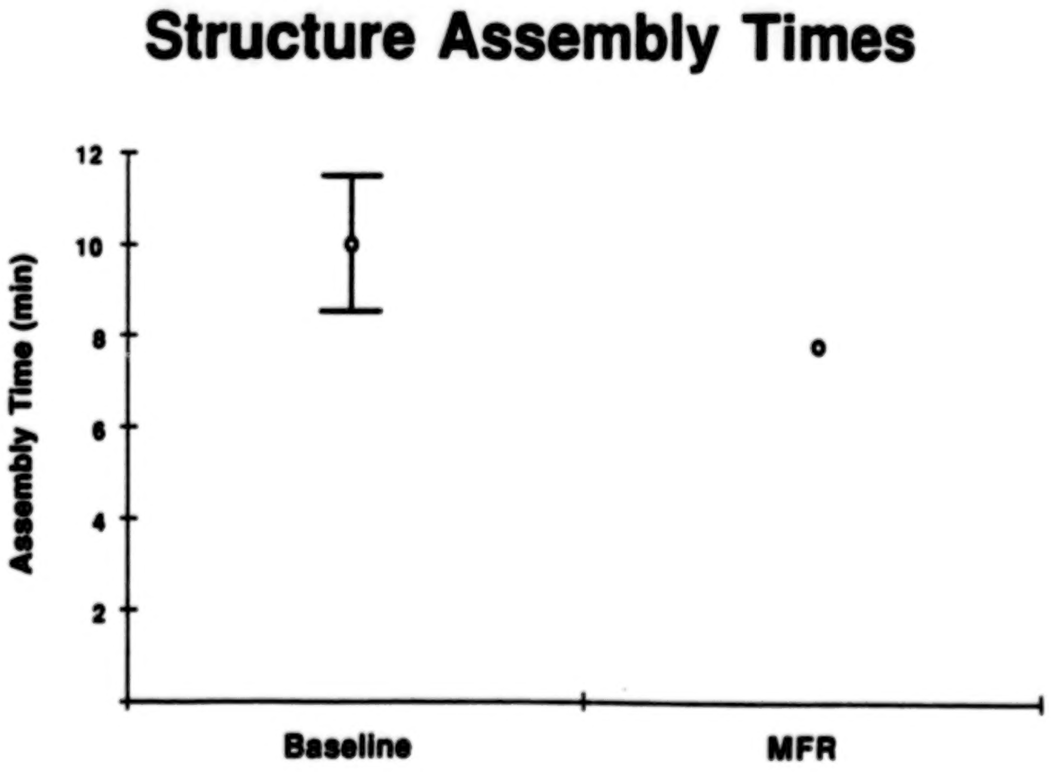
Task Time Distribution – Beam Alignment Task

The beam alignment task was assumed to begin with the completion of rotation at the approximate orientation of the cluster connection to be made with the beam. At that point, the crewman would initiate a series of fine torques to the beam, to align it to within the ±1° angular tolerance of the EASE connectors. As this chart illustrates, the distribution of times is very similar for the two environments, indicating that there are no major differences in the mechanics of this activity. However, the slightly greater mean time for alignment in neutral buoyancy is again probably due to the damping effects of the viscous environment.



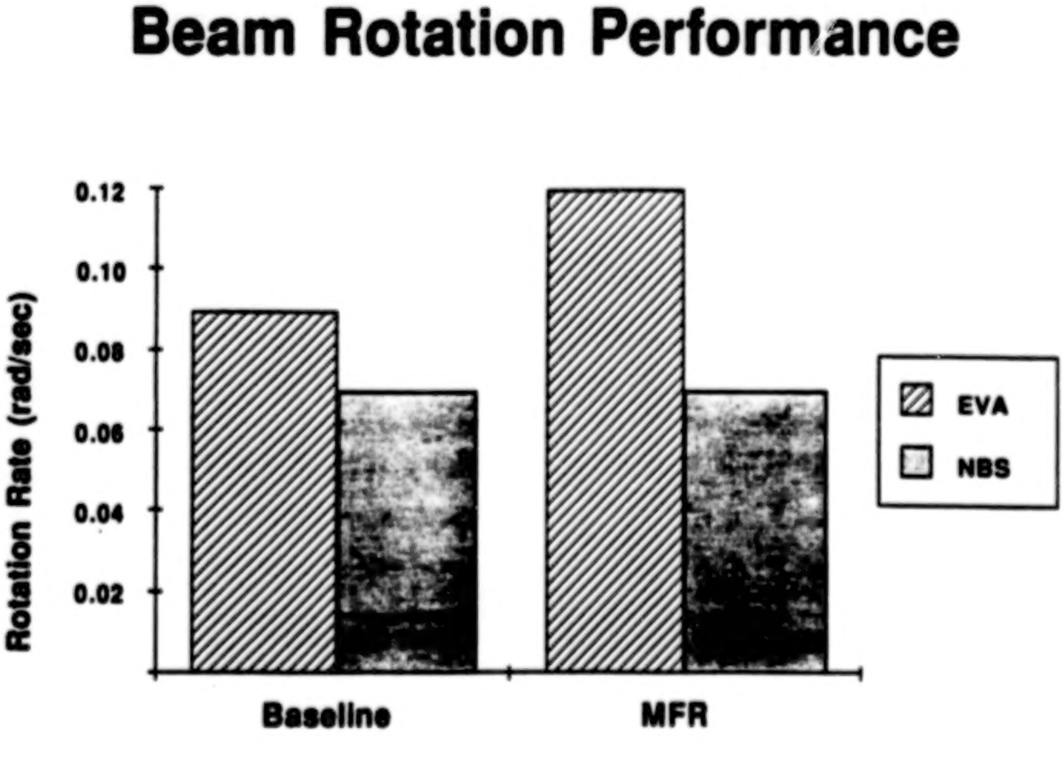
Structure Assembly Times

Eight EASE structural assemblies and disassemblies were performed on the first EVA, with an average assembly completion time of 10:00. This chart also shows that the standard deviation for these assembly times was approximately 1:40. During the second EVA, one EASE assembly was performed with the crewman in the "high man" position using the Manipulator Foot Restraints (MFR) attached to the shuttle Remote Manipulator System to provide a fixed body restraint during all activities. The time of this single assembly, corrected to eliminate other intervening tasks such as the double-beam manipulation, was 7:50, indicating that this operating mode could provide approximately a 20% savings in assembly time. This conclusion will be further examined in the following charts.



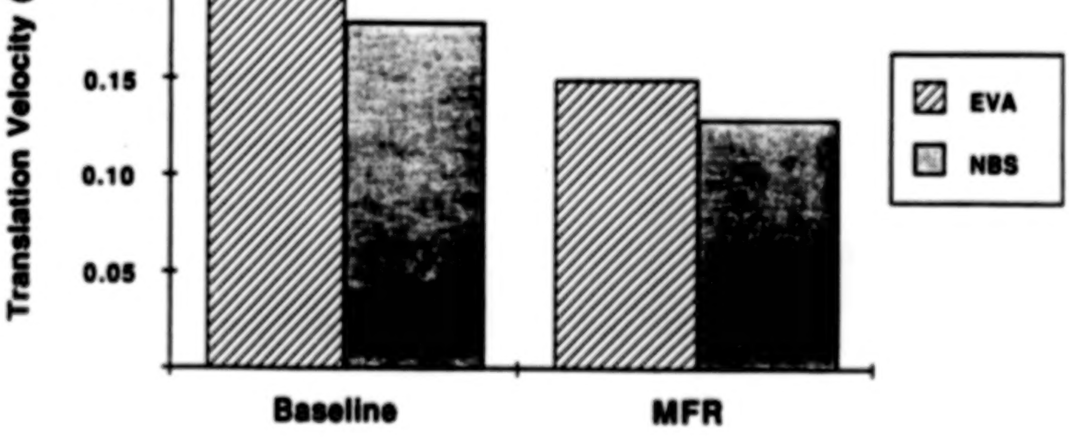
Beam Rotation Performance

A time and motion analysis of the beam rotation task showed the attached trends for both free-floating (baseline) and body-fixed (MFR) activities in neutral buoyancy and EVA. As may be seen, the form of restraints did not affect the rotation velocity of beams underwater, indicating that the crew tended to rotate the beams at an effective terminal velocity. In space, however, fixed body restraints allowed an average increase in rotation speed of approximately 20%. This form of large-scale manipulation is clearly improved by the presence of body restraints to resist the counter-torques of the rotation task.



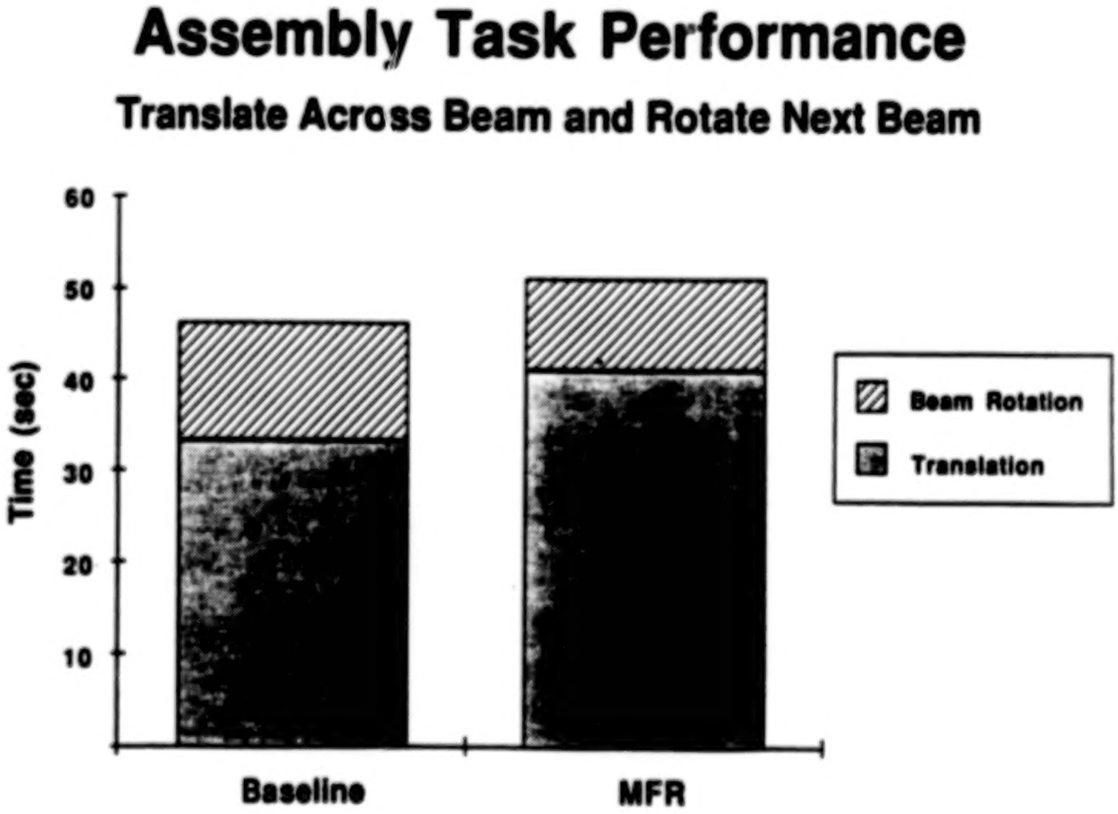
Translation Performance

The other significant difference in high man assembly procedures between baseline and MFR activities was in the mode of translation between worksites: the crewman maneuvered hand-over-hand along the cross beams in the baseline case, and was moved by the RMS during MFR activities. This chart demonstrates the average translational velocities for both modes in neutral buoyancy and space. Translational velocity is slower underwater for both operating modes, again due to water drag, as well as non-standard control modes for the RMS simulator at the NASA Marshall Neutral Buoyancy Simulator. Of particular note, however, is the large difference in velocities between manual and RMS translations. Movement of the MFR was slowed by the standard operating speed of the RMS, as well as the forward location of the EASE/ACCESS experiment in the payload bay, which required significant attention on the part of the RMS operator to avoiding joint singularities.



Assembly Task Performance

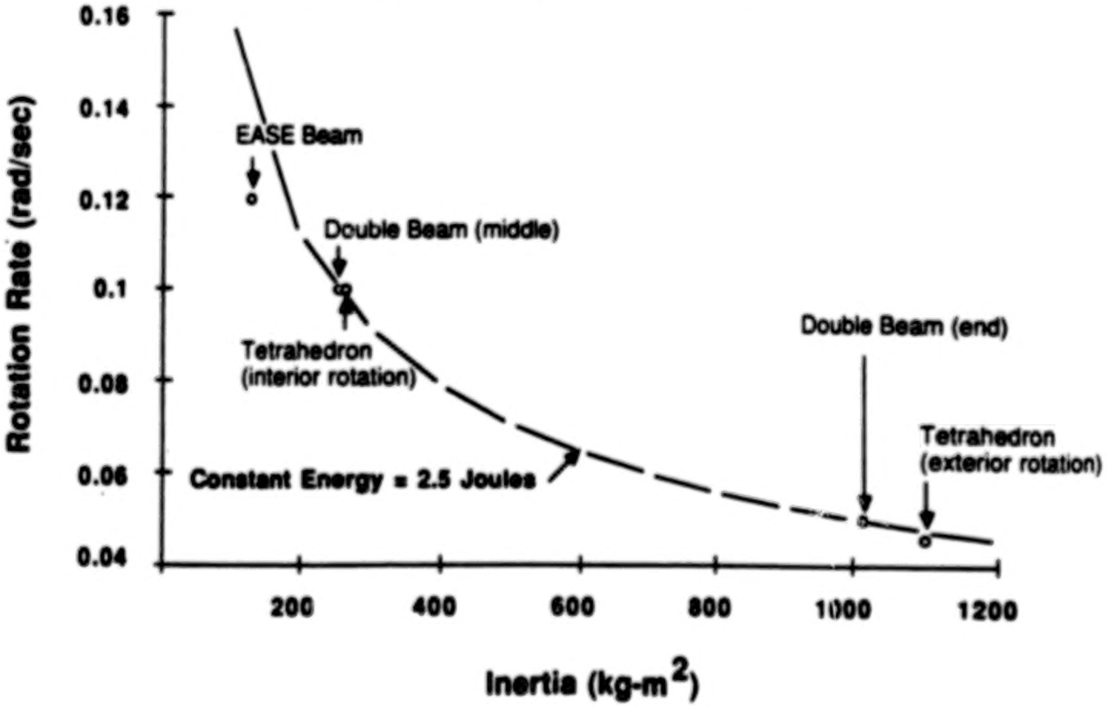
Combining the results of the previous two charts, the critical activity for the high man may be abstracted down to a simple compound task: translate along the length of a cross beam, and rotate the next cross beam into position. This occurs three times in the MFR assembly procedure, and twice in the baseline. As this chart shows, although the fixed body restraints facilitate the beam rotation task, any benefit is lost when including the slower translation rates achievable with the MFR and RMS. The net productivity of the high man goes down with the MFR, even excluding the overhead required with a third crewman (RMS operator) directly involved with the assembly. A review of all the data in fact indicates that the faster assembly of the MFR procedure is due to increased productivity of the lower crewman: since he is not required to translate up and down a riser to assist in the completion of the first cross beam, his time is better optimized in attaching riser beams and passing hardware to the high man.



Rotation Rate – Moment of Inertia Correlation

As mentioned earlier, one of the key elements of the EASE experiment was to obtain quantifiable data on the manipulation of large moments of inertia. During the two EVAs, the flight crew manipulated three different hardware items: the (normal) single EASE beams, a double EASE beam (simulating a space station heat pipe structure), and the complete EASE tetrahedron. The double beam was maneuvered through rotations at both the midpoint and one end; the tetrahedron was manipulated along internal and external rotation axes. In this way, data was obtained on five separate moments of inertia. Plotting the mean rotation rates versus moment of intertia, it was discovered that four of the five data points lay almost exactly along a line of constant rotation energy. It is extremely interesting that this should be the case, although it might be suggested that the crew mentally integrated the torque impulses to insure that all the various components, once moving, could be brought to a stop again with the same effort. One of the immediate priorities of the EASE data analysis team is to attempt to expand this correlation through obtaining other rotational data points from ACCESS or previous EVAs.

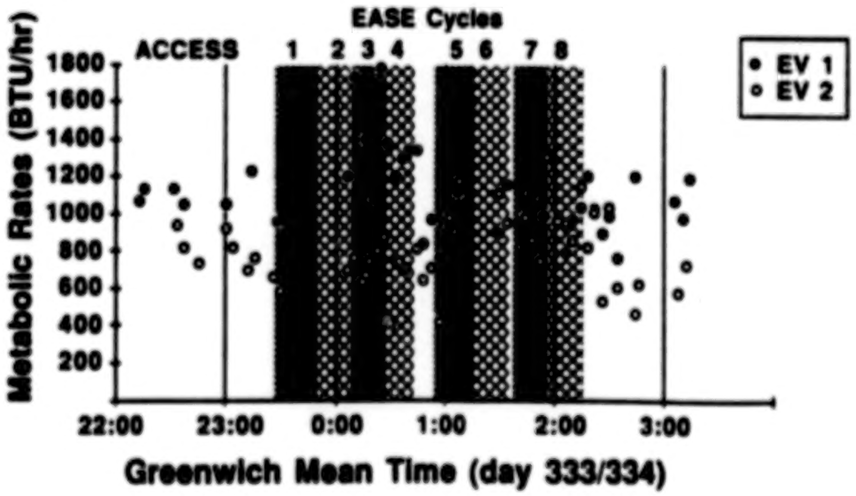
Correlation of Rotation Rate with Moment of Inertia



EVA 1 Metabolic Rates

The Extravehicular Mobility Units (EMUs) used on STS 61-B were for the first time instrumented for biomedical readouts. While the orbiter was in communication with the ground, suit parameters were read out at 2-3 minute intervals. This data was available post-flight for estimating crew metabolic rates, as a quantitative indication of workload. This chart shows the measured metabolic rates for both crewmen during the first EVA. Salient points to be noted include the fact that maximum metabolic rates for both crewmen occured during the time they were working the "low man" position of EASE; minimum metabolic rates are observed while the crew are in the "high man" position without fixed body restraints; and that the data is too coarse for definite correlation of work loads with specific tasks. While this data seems to show that physiological demands during unrestrained assembly is even lower than that of the fixed assembly routine of ACCESS, it has been pointed out by the flight crew that this biomedical reading is not indicative of the fatigue of selected muscle groups, especially of the wrists and hands, which they noted during EASE high man activities.

EVA 1 Metabolic Rates



EASE Results

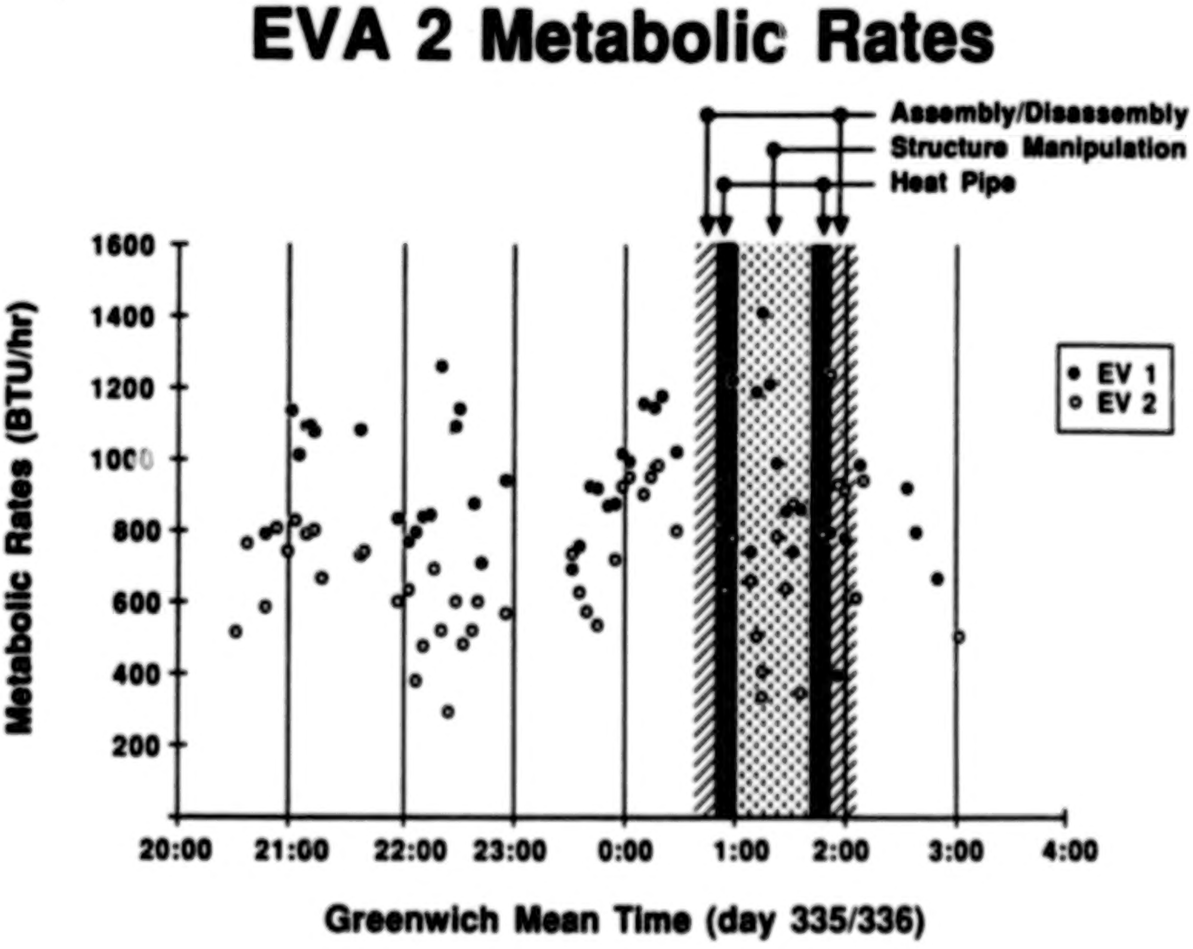
The bulk of this chart is self-explanatory. It should be pointed out that an analysis was performed, based on the stereo film data obtained during the baseline EASE activities, which enabled the estimation of energy being applied by the crewmen external to the suits. These energy levels are uniformly an order of magnitude below that shown by the metabolic rate insturmentation; even including generous estimates for basal metabolic rates and muscle group efficiencies, a substantial fraction of the crew work output is not evidenced by external motions. This energy can only have been dissipated in three modes: motions below the discrimination level of the stereo film reduction methods, closed-path kinematic loops, and work against the inherent stiffness and friction of the pressure suits.

EASE Results

- The 61-B flight crew showed an 18% reduction in assembly time on-orbit vs. comparable NBS.
- Task analyses indicate no unequivocal differences between EVA and NBS for the component tasks of the EASE assembly.
  Time scatter for tasks is generally less in EVA than in NBS.
- Dynamics reconstructions show that mechanical tasks in space are performed faster and with less externally-applied effort than in NBS.
- Unrestrained EV operations, including manipulation of large masses and moments of inertia, are feasible.
- Comparative analysis shows that RMS/MFR assembly operations are marginally faster than unrestrained, due to procedural improvements.
- No quantifiable parameter from EASE indicates a marginal return from the wide-spread incorporation of body restraints which would justify their incorporation in all EVA scenarios.
- Rotation of large objects appears to be performed on a basis of constant rotation energy imparted to the task.
- The largest single factor in energy expenditure is the suit.
- No significant difference exists in energy output based solely on worksite configuration, although coarseness of biomedical data did not permit unequivocal conclusions.

EVA 2 Metabolic Rates

As in the previous chart, results of the biomedical instrumentation system are too coarse for detail correlations with tasks. Maximum heart rates for EV1 again occurred during "low man" activities, most notably the replacement of a balky pip pin in the structure connection mechanism. Again, no mathematically significant difference can be detected in biomedical workloads between the MFR activities and corresponding high man activities of EVA 1.



Current MIT Research Objectives

This chart emphasizes that, while EASE has provided a wealth of data only briefly touched on in this presentation, it has opened up new vistas in space operations research. None of the objectives from the initial chart are resolved, although all have been addressed and much better refined by EASE data. Instead, the data from EASE have led to the development of a wealth of research topics dealing with human and machine capabilities in space. Of special note is the fact that the EASE experiment has for the first time allowed a quantitative connection to be established between the previously separate topics of anthropometrics, kinematics, dynamics, and energetics. Further study of the interrelationships of these areas holds the promise of a "Unified Theory" of space simulation, which would allow meaningful estimates of forces and energies required based solely on dimensional and kinematic descriptions of tasks.

Current MIT Research Objectives

To investigate and, to the extent possible, quantify the capabilities and limitations of humans *and machines* in the environments peculiar to space and space flight simulation

- **Performance**
- **Adaptation**
- **Physical Workload**
- **Dynamics**
- **Timelines**
- **Simulation Media**
- **Task Aids**
- **Optimal Roles of Humans and Machines**
- **Control Station Design**
- **Novel Concepts**
- **Simulation Technology**
- **Automation Integration**
- **Microgravity Anthropometrics**
- **Unified Theory of Space Simulation**

SUMMARY OF STS FLIGHT 61-B

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Participating in this discussion are Dr. Mary L. Cleave, RMS operator for the EASE/ACCESS experiments on STS Flight 61B and Lt. Col. Jerry L. Ross, EVA crewman for the EASE/ACCESS experiments on STS Flight 61B.

JERRY ROSS:

We've got some comments to make and then hopefully we've got some time for questions and answers. Well, I've kind of jotted down some notes flying in here the other day and I put them into two categories; one I called lessons learned and the other one is "surprises." Some of them can cross over either way and maybe don't fall into either category appropriately but let me go through them real quickly.

First one is the Weightless Environment Training Facility (WETF) is a good simulator. By that I mean the neutral buoyancy simulators we have - if you have high fidelity hardware in the tank and with the little bit of windage that we've learned through previous flight experience, you can really give a very good estimate as to how long a task will take, whether it's a reasonable task to do or not, and you can learn any potential problems pretty darn well.

Second comment I'd like to make is when we start considering things like space stations or starting to build larger structures in space, we need larger facilities. The WETF tank down at Johnson Space Center (JSC) is 33'x78'x25' deep and it barely satisfies the Orbiter cargo bay itself, when we start getting into payloads as small as ours or to a space telescope or something like that, we really have problems trying to simulate in a reasonable manner the task that we have to do. The Marshall Space Flight Center (MSFC) one is better, but it's not really satisfactory as far as the crews are concerned because once you get in close to a flight you don't want to have to be traveling for a good period of a day or several days going back and forth to a tank facility that's located away from your home base. That's because of many reasons - just trying to integrate the schedules to do the training. As the principal investigators (PI's) and Kitty Havens and the folks know, the last month to two months to three months is a very integrated, long hour type push. You want to be able to do that training in an integrated and a rapid manner and not have to spend a lot of time traveling to and fro. Our normal training cycle at JSC in the WETF consists of about a three hour run and normally we operate our suits at about three and a half pounds per square inch (psi). Because Woody and I knew that these were going to be very hand intensive, very long extravehicular activities (EVA's), we asked for and got approval from the safety folks and everyone else to elevate our suit pressure to almost four psi. We asked for four, and were approved for four but the hardware limitations were such that we operated probably more around 3.9 psi in the suits. We also asked for longer runs and, as you saw in Kitty's presentation yesterday, nominally we ran for four hours in the tank and sometimes, in integrated sims, etc., we ran for a considerably longer period. We also tried to keep moving as long as we were in the tank, just to try to build up our endurance. Woody and I also hit the weights quite a bit, especially during the last two or three months to try to get in the best condition we could. I really think that was a good idea because we worked our tails off out there and we were tired when we got back inside, especially on the first EVA. We worked, especially Woody and myself, with the PIs and the Marshall folks very early on in the EASE/ACCESS evolution and I thought that was a great way to do business. I would strongly encourage people to try to get crew involvement as early as absolutely possible. We got in some early runs at MSFC, we helped make some comments that I think helped the overall evolution of the process, and we also learned a lot of things. Then when the initial request for two EVA's, one for ACCESS and one for EASE were not approved, Woody and I put our heads together at JSC, went out, knocked on some doors and got the second EVA, the DTO EVA put together and approved and I think that proved very beneficial for demonstrating the capabilities that the Space Station program really wants to know about.

The suits worked great, I can't say too much about them, they were marvelous machines, we never had any real concerns about them at all, they checked out and worked properly. I have two comments about them. First of all, Comm Mode B, which you probably didn't hear much about: one of our channels on our communications (comm) systems between the Orbiter and the EVA crewmen had some interference that was caused by some of the electronics inside the suit. The first time that it had ever been observed on flight, both suits had it. Post mission, they were able to reproduce the problem and they've got fixes in work at this point, in fact, I think they're probably fixed. The other problem was one that Woody and I had both seen pre-mission, that happened to be with the gloves. We transitioned to a new series glove, Series 3000 gloves, which were pretty much custom made for both Woody and myself. The gloves overall are an improvement over the earlier gloves we had in the Shuttle program, however, they had one problem in the thumb area of the glove, which both Woody and I experienced pre-mission and on our long tank runs: numbness in the thumb, which we, after talking to the doctors in our office, attributed to irritation of the nerve sheath along the base of the thumb. Normally, after a couple of days following the tank run, the thumb feeling would return. While we found it an irritant and something we didn't want to live with for the duration of the Shuttle program, we found it acceptable for our mission. About one hour into the first EVA, both of my thumbs were totally numb from the first joint on. My left thumb was numb for probably a month to a month and a half after we landed. Since that time, the folks have done some modifications to my gloves and I've done a series of runs using the EASE/ACCESS hardware under simulated flight conditions in the

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tank and found that fix to be satisfactory for me. Some of the other folks in the office are still having, I think, some problems with the gloves, but we're making progress.

We felt, and several other crews felt that we ought to have an I-comm or an intercom mode between the EVA crewman and the crew in the Orbiter such that everything we say doesn't automatically get relayed to the ground, which is currently the case. Anything that we say outside is automatically relayed to the ground and that sometimes inhibits the free flow of information or conversation because we know that there are other people listening in on a party line. Hopefully the suits that we have in the future will incorporate that.

This is the first time, as I mentioned yesterday, that a real time suit telemetry modification had been added to the suits. It did not change in any way the flight rules of how we would react to any type of suit problems and in fact, during the flight it actually helped us somewhat. On the second EVA, we got a call from the ground just prior to a loss of signal that both Woody and I could expect battery messages to come up on our caution warning displays on our suits telling us that we were essentially out of electrons and we did get that during the loss of signal period but that was due to a software problem that had not been updated in the caution warning system. They had put in larger batteries that had better energy output than what the software was registering and therefore we were told to ignore the messages when they came. We did and even though we knew all that stuff, it sure was a nice reminder to have in real time.

Woody and I have both pushed for, and previous crews have pushed for rest days between EVA's; we think that that is probably not only a good idea, it's probably required. Woody and I, after the first EVA like I said earlier, were both extremely tired, especially in the hands and forearms. Even though we could have gone out the next day on another EVA had we needed to, the day in between to recharge the suits and to refresh the body surely was welcome. And, I think in our case, we would have not performed as well on the second one had we gone out the day after the first one.

We've already talked about the ease with which we manipulated the structures, it really amazed me. I was using just very light finger forces to move those structures around and it was just very pleasant. I grabbed the axis at one end and I could have used it as an alignment aid. I spotted the moon right in the middle of the triangle, and I could have held it there indefinitely with very, very light forces. I shook the axis truss, it felt very rigid to me, that's a qualitative comment. The EASE structure had somewhat looser joints and when I shook it, it responded very much like it did in the water tank, it had a little bit of a ring to it. Freefloating, in my way of seeing things, is not the way to assemble structures in space. For limited applications it can be done, as we have demonstrated, and limited is dependent upon the nature and requirement of the task. But I can't overemphasize the fatigue that was built up in our hands and forearms trying to maintain body position while we were torquing those beams around. Even if you had less massive beams to move around, I still think that the 400 pounds of mass that you are trying to position and maintain position on really is fatiguing to the hands. We did use two people, one on each end of the beam when we were putting up the aft crossbeam on EASE. That didn't seem too bad, because you had one hand that you could kind of translate with and the other hand that you are holding on to the beam with. That's all you really had to do, the beam kind of went with you, it was another part of your body almost; that way it worked pretty nicely being in an unrestrained condition. But we did feel, even though Dave showed some data that manipulator foot restraint (MFR) times in actuality may not have been any faster, from the top man's standpoint anyhow, we felt that the MFR really proved to be a great benefit to the guy on top. That's because he didn't have to maintain body position, his feet did it for him and therefore, all the energy expended was in manipulating the beam, which was a very minimal amount of effort.

I'd like to talk about suit pressure a little bit. Woody and I worked in the suits for a total of over twelve hours outside and we had a suit pressure of 4.3 pounds per square inch (psi). I am currently working on Space Station, and the current concept there is the Station will operate at a pressure of 14.7 psi. And because of prebreathe concerns, the nitrogenization and bends concerns, that's pushing us to a requirement that says you have to operate out of a suit that has an 8 psi pressure - that's if you want not to spend extended durations prebreathing O2 environment to scrub out the nitrogen from your body. Even though I know there is a lot of effort going on and I have already evaluated, at least in a glove box format, new gloves coming down line that hopefully will address the 8 psi concerns, I've not found anything yet that comes close to allowing you to do in an 8 psi suit what we did at 4.3 in the Shuttle suit and that really concerns me, because we are really pushing along in the Space Station business with a 14.7 cabin and the cure is an 8 psi suit. Unless we make some quantum jumps in the glove capabilities, we are really degrading our EVA capability by the direction we're going at this point. Once I've had a chance to evalute the hardware more fully, maybe I'll change my mind, but that would surprise me if that happens.

Some surprises: the space suit out there in the vacuum of space is stiffer than the one we practice in. And in fact, it is a lot stiffer. Two reasons I think: number one it's a new suit as opposed to one that's been worn many times, and secondly, it's a lot colder out there - the water tank we maintain at 90 plus degrees so that the scuba divers don't get cold after a long period of time in the tank, and out there, I'm sure the suits are much colder and therefore much stiffer. That makes it a lot harder to get in and out of foot restraints, and requires a lot more energy to be expended. Woody and I probably got in and out of foot restraints more than any other crews have ever done on the EVA's, and after both EVA's, our knees were pretty sore because of the stretching of the ligaments on both sides of the knees - getting in and out of the foot restraints.

One of the surprises that I had: tether management is always a pain and I thought maybe I had found a way to get around that a little bit, in the water tank by connecting the harpoon - the little attachment device that was used on the EASE beam - to a mini work station (that's a little tool caddy kind of carrier that mounts under the front of the suit). It has a self tending tether on it that you can either lock off at some condition or it will self tend and retract any time we let go of it. So I had attached my mini work station tether to one of the harpoons and that's the way I was going to tether the beams when I was up on top of the EASE. In the water tank that seemed to work just fine. But when I got out there and tried using it for real in zero G, I found that the returning forces on that tether were too much and they tended to battle me too strongly when I was trying to position the beam - it was always trying to torque it off in a direction I didn't want to go. And so after the first assembly of EASE on the top, I opted to lock off that tether after I had pulled out a given length of the tether. The second time it worked better yet I had too much tether pulled out, and it tended to snake around anything that was anywhere close. Finally, by the third time on top of EASE, I had just had about the right length of tether out and it worked much better. Even though Dave's data showed that the fourth cycle that I was on top of EASE was longer than the third or second, I felt that that was by far the best assembly that I had done from the top. I felt like I got into position, rotated the beams at the proper rate, and I felt like the assembly task, the making of the connection went much more smoothly than any of the other cycles had. So it's kind of interesting to see the data that he presented.

We always try to do fit checks of all flight hardware to make sure that we aren't going to get any surprises when we go out there and start handling it for real. We did a pretty good job of that, in fact we went through a full blown crew equipment interface test down at the Cape on the EASE active hardware, and you saw some slides of that yesterday. One thing we neglected to fit check however, was the little plastic clips that we use to hold the rope against the ACCESS structure in simulating the cable run, and wouldn't you guess that those little clips had been built a little bit differently from the ones we used for training. In fact, the rope would not go into the notch that was cut out for holding the rope on the side of the structure. But that didn't prevent us from doing the task. Fortunately, the rope was pliable enough that you could just kind of mash it in there and it held just fine. But if there's ever a lesson learned, it is to check everything, and if anything can go wrong, it will, so just do it anyhow - even if they tell you don't worry because we've already done it, do it yourself.

We did have a couple of hardware problems. One of them was the ACCESS strut canister latch that was talked about by John Rodgers yesterday. My guess is that probably one of us, either Woody or myself, probably dinged it at some point as we were translating it around out there, and just bent it a little bit, such that it would not relatch. But again that was one of the things we had "what-ifed" pre-mission. We had gotten approval through safety and through engineering folks that one latch was sufficient and there was no concern real time, we just pressed on, we just noted it and there was nothing else said. The EASE base cluster pip pen - I think from us being up on top of the structure and putting some fairly large motions into it, we probably created some galling down there in the pip pin area. When I pulled the pip pen out, it came out freely. I didn't think there was any concern at all about getting back in, but when we tried to reinsert the pip pen, then you saw some of the energy spikes - but you didn't hear some of the things I was thinking. After about three, four minutes of trying to get that pip pen reinserted, Woody and I just grabbed the spare cluster that was out there on the MPESS, and pressed on with the activity. Again I think a well trained crew given some options, will grab those real quick, and we were already pushing on by the time the ground came up with any suggestions.

Another surprise to us was because of the concerns that were alluded to yesterday about excessive wear on the thermal garments - the outer thermal cover of the gloves. Early in the training and development process, the glove people went off and developed a new outer cover that had some kind of a rubberized material that they put onto the fingers - along the inside of the fingers and the palm of the glove. And that stuff worked great. We saw essentially no abrasion at all on those coverings. We did see a little bit of evidence of where the rubber was starting to pull away from the rest of the thermal garment material, but it was not of concern at all. In fact, it proved to be another surprise in that the Kapton covering that was on the ACCESS struts wanted to grab onto that rubber material in the gloves and not let go - to the point that once or twice, Woody or I had to pull those struts away from each other. It caused us to literally have to open our gloves further than we really wanted to to let go from the struts.

I guess one other thing that might be noted, if you add up all the hardware that we assembled and disassembled, we actually built quite a bit of length of truss out there, and I think that given the proper setup for Space Station, we'll be able to do that in a very efficient manner in the future.

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MARY CLEAVE:

I'm going to talk a little about the arm which was just a part of EVA II. The arm which was built by the Canadians is a great tool. It was not designed to be used in this particular way, but it worked wonderfully. We were able to get the rates increased with the help of the Canadians, and also the people that manufacture the MFR. Actually it was moving about twice as fast as it had previously, and a previous crew had said that the lower rates on the MFR were really restricting what they could get done because it took so long to get a guy from A to B. I think we would really have been in trouble if they didn't have those increased rates. Jerry said that it really didn't bother them when I bounced them around. I tried to hamhand them and he really would react against the arm. The arm will actually displace about a foot if you would really react against it because it's very light structured, electric and has little motors. It will only work if there's no gravity, so on the whole it worked real well. I would like to say if we ever do get a big pool to train in, it would be nice to have an arm in it that's like a flight arm. The guys at MSFC were very nice to let me use their engineering arm. It was not a trainer, and it really helped us to integrate. Actually, the only time we did this task all together was when we got up on orbit which made it more fun, but I think it would probably be a little easier on everybody if they had at least gotten a little more integrated to start with. Jerry and Woody spent the 45 minutes down in the air lock before they went out - when I was supposed to give them a ride that day - telling me what a great guy I was, so I figured maybe there was a little anxiety there.

JERRY ROSS:

Well you know, guys are always concerned about women drivers.

MARY CLEAVE:

That's right. That was it. All because I was a girl, I know. The surprises I had on orbit: the first one that was most important to me and which I mentioned during the movie was actually trying to tell small motions at the tip of the arm against the moving Earth - against the truss where you didn't want to bump the truss. The second problem we ran into was due to the fact that EASE/ACCESS was manifested in the front of the payload bay, which meant the arm was working the front of the payload bay, so we were always working around singularities. It would have been easier if it had been manifested further back in the payload bay, but we had three satellites which brings up the third problem. Because we had three satellite support structures in the back, we couldn't use the three back payload bay lights. That meant that we were totally dependent on the two front payload bay lights. So you're going through 45 minutes of darkness every hour and a half, it would be nice with that much darkness on a regular basis to have adequate lighting. I think you had adequate lighting.

JERRY ROSS:

Yeah, I always felt that I had plenty of lighting. We used the bulkhead light on the forward bulkhead, as well as the two forward payload head lights, and once or twice when I was way up on top of the ACCESS truss at night, I went ahead and put on one or two of my helmet lights.

MARY CLEAVE:

Yeah, he has little head lights, whereas if I was looking at him moving, I was much more dependent on Jerry's ground controlled approaches (GCA's) - his telling me where he had to be because I really couldn't see as well. And it would help to have running lights on your arm because then you could see how the arm was configured especially if you're in a regime where you can get into a singularity - where you get into the problem you can't resolve and the arm is going to move in some way, but you're not sure where it's going to move. So you don't want to have that happen right next to a structure with your friend on the end of it. On the whole, the arm operations worked a whole lot better than I expected them to, these guys were a whole lot easier to move around, and they were a whole lot more cooperative in space than they were in a tank at MSFC.

JERRY ROSS:

Mary did a super job. If we wanted to go two inches in one direction or the other, that's where she put us. That was great.

MARY CLEAVE:

Thanks. Even though I'm a girl huh? Great.

JERRY ROSS:

Now where's my five dollars? We have time for a few questions.

QUESTIONS AND ANSWERS

QUESTION:

If an EVA crewman is working 45 feet up from the cabin, would it be better to have the person inside the cabin with limited visibility operating the arm, or would it be preferable to turn the arm into a cherry picker operation where the EVA crewman could operate the arm?

ANSWER, MARY CLEAVE:

In my opinion, since I'm an arm operator, I want to keep control. With the arm in its present state, and especially in the configuration we were working with (Jerry standing on the end of it), he would not have had the visibility beneath him to tell when he was getting into problems with a singularity or a reach limit on the arm. I think he would have ended up driving himself into more problems than I could avoid by operating it from inside.

JERRY ROSS:

I agree with that. I think when you put control on the end of the arm, number one, it gets in the way of where you want to work. You have a very limited reach envelope where you can really work with two hands in an ideal fashion, and you don't want to clobber that up with something if you can help it. Secondly, as Mary said, you can't see the arm configuration behind you, and a lot of times you really have limited visibility to any structure that's relatively close to you as well. Third thing is as long as you've got an Orbiter up there, and you're working off of an Orbiter, you've got two or three people inside that are relatively underutilized compared to the guys that are out there whose utility and time you're trying to maximize. Therefore, I think that you ought to take advantage of the additional people inside.

MARY CLEAVE:

One of the concerns for the arm configuration was a decision made not to take up the software space to put any software blocks in to protect the Orbiter. So you can run that arm into the Orbiter anytime, which you don't want to do. So that's why you tend to be a little cautious.

JERRY ROSS:

Okay, I think we'll hold the rest of the questions to the panel who will be glad to answer any of them then. Thank you.

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OVERVIEW OF CREW MEMBER ENERGY EXPENDITURE DURING SHUTTLE FLIGHT 61-B EASE/ACCESS TASK PERFORMANCE

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OVERVIEW OF CREW MEMBER ENERGY EXPENDITURE DURING SHUTTLE FLIGHT 61-B EASE/ACCESS TASK PERFORMANCE

In this paper we report the energy expenditure of Shuttle Flight 61-B crewmembers during extravehicular performance of EASE and ACCESS construction system tasks. These data consist of metabolic rate time profiles correlated with specific EASE and ACCESS tasks and crew comments. Average extravehicular activity (EVA) metabolic rates are computed and compared with those previously reported from previous Apollo, Skylab and Shuttle flights (ref. 1, 2, 3).

These data reflect total energy expenditure and not that of individual muscle groups such as hand and forearm. When correlated with specific EVA tasks and subtasks, the metabolic profile data is expected to be useful in planning future EVA protocols. For example, after experiencing high work rates and apparent overheating during some Gemini EVAs (ref. 4, 5) it was found useful to carefully monitor work rates in subsequent flights to assess the adequacy of cooling garments and as an aid to preplanning EVA procedures.

FLIGHT 61-B EVA-1 ACCESS METABOLIC RATE PROFILES

Figure 1 illustrates the rates of total energy expenditure of each crewmember during the ACCESS phase of EVA-1. The mean metabolic rates were 1144 BTU/Hr for EV1 and 892 BTU/Hr EV2. EV1 and EV2 are crewmember designations. Individual tasks are shown on the top of the figure, coinciding with the timelines. As would be expected, the highest work rates were during the build-up of the bays and again during the disassembly. These data are based on oxygen utilization, the average energy release per unit of oxygen being 4.82 Kcal/liter or 380 BTU/mole (ref. 6). ACCESS required considerable work by the hands, but the total work output does not reflect hand fatigue or difficulties with handgrip strength. EVA crewmembers were asked to comment on relative thermal comfort. For this reason both made multiple comments on hand, foot and extremity cooling. These comments should not be interpreted as complaints, but merely reporting feelings of coolness as the heat removal system operated.

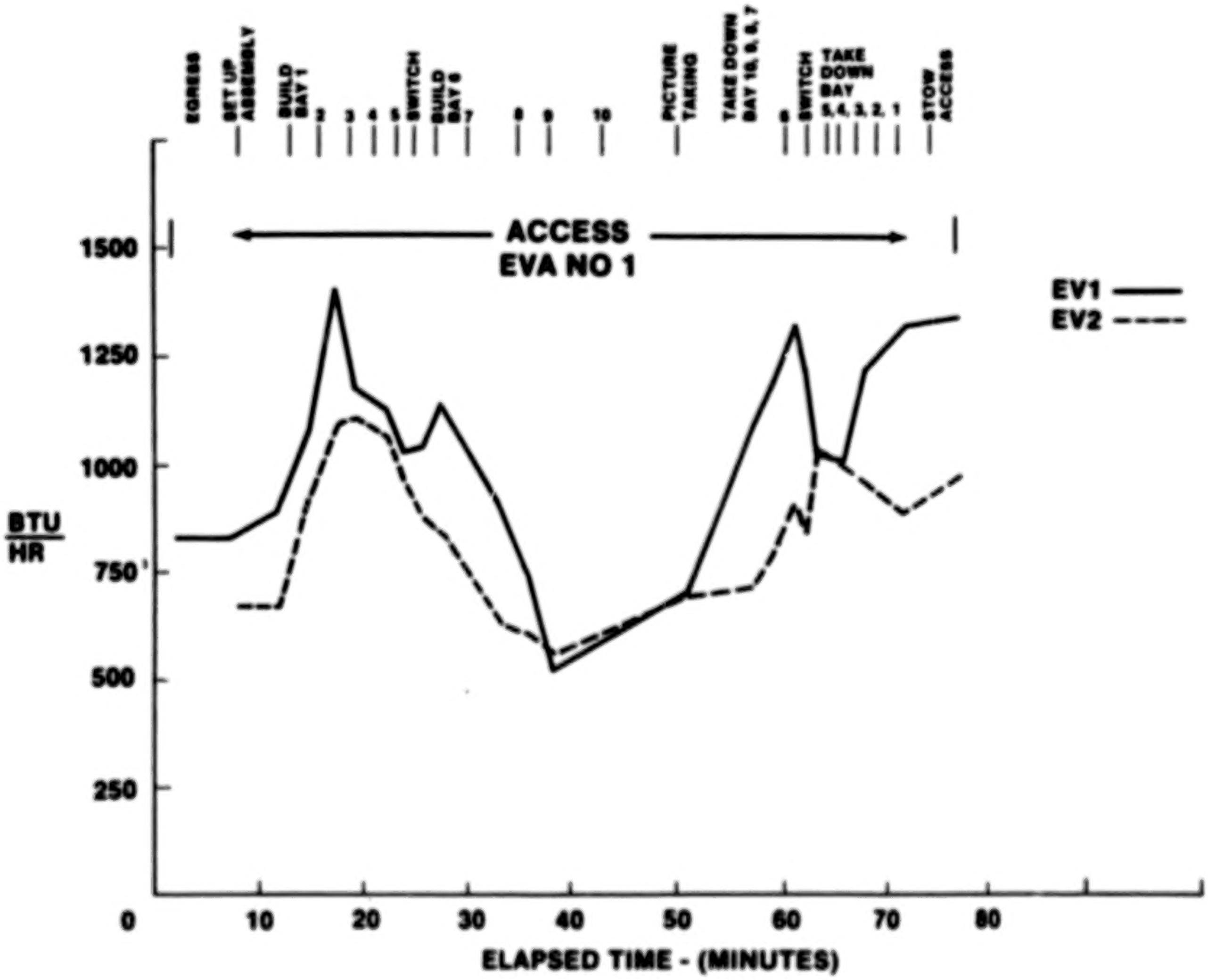

Figure 1

FLIGHT 61-B EVA-2 ACCESS METABOLIC RATE PROFILES

Figure 2 illustrates the rate of energy expenditure of each crewmember as a function of time during the ACCESS portion of EVA-2. The mean metabolic rates for the ACCESS portion of EVA-2 were somewhat lower than during the first EVA (EVA-1), i.e., 924 BTU/Hr for EV1 and 680 BTU/Hr for EV2. Again, the higher rates occurred during the build-up and disassembly of the bays.

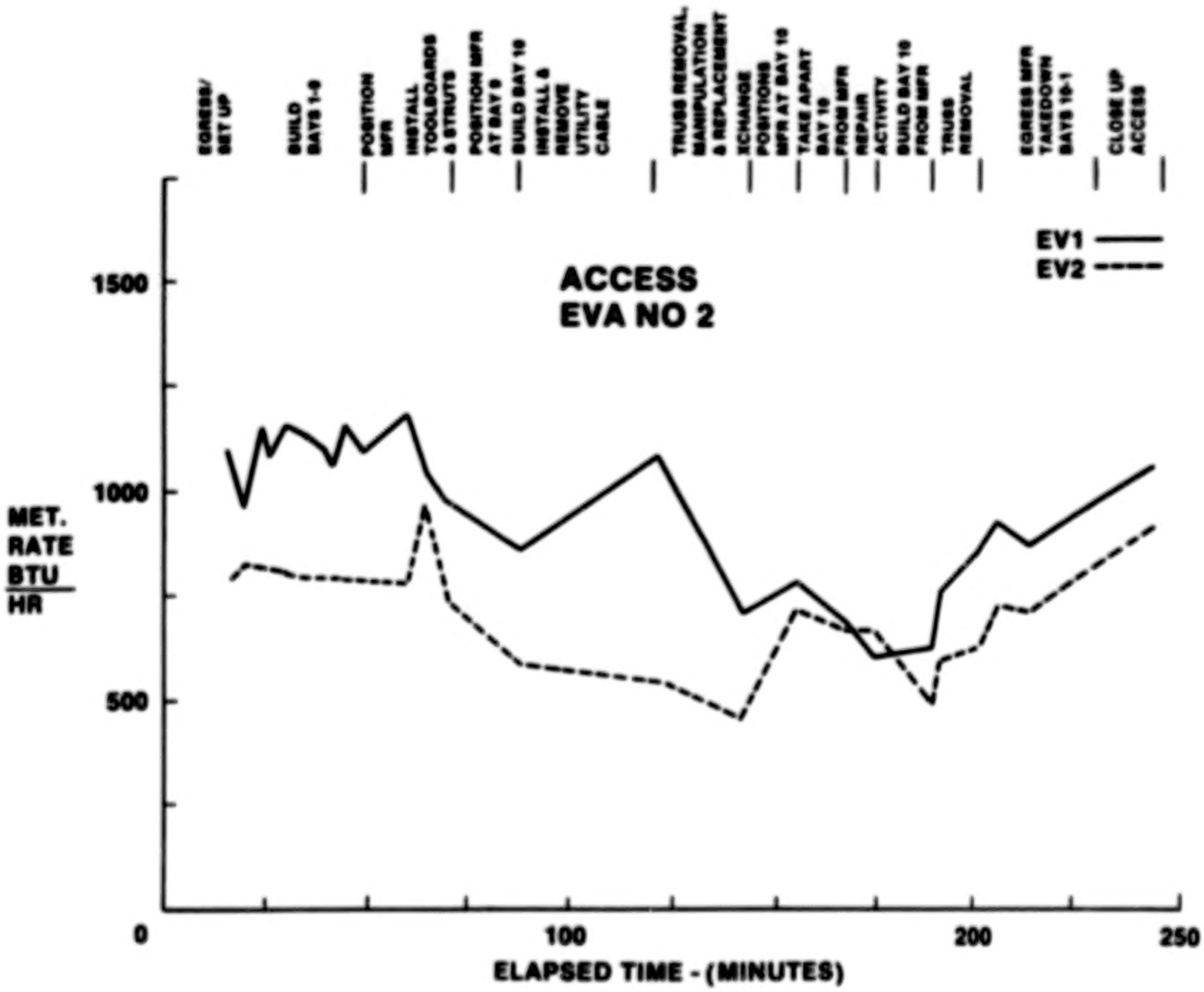

Figure 2

FLIGHT 61-B EVA-1 EASE METABOLIC RATE PROFILES

Figure 3 illustrates the rates of total energy expenditure of each of the two crewmember during the EASE phase of EVA-1. The highest work rates are recorded for EASE 3 and EASE 7 subtasks. EV1 was in the low-man position during the first four assembly/disassembly cycles while EV2 was in the high man position. After they switched positions EV2's work rate increased significantly as he assumed the low-man position. The low man was required to unstow each of the six beams, connect the three vertical beams to the base cluster, translate to the top and help join one of the horizontal beams to the vertical beams, and then rest on the beams as they were removed. Both crewmembers reported that the task was fatiguing for the free-floating crewmember who had to maintain correct body position while using hand and forearm strength to torque the beam into place. This points out the fact that the total metabolic work rates may not reflect the crewmembers' fatigue caused by difficulties with one set of muscles such as the arm and forearm area.

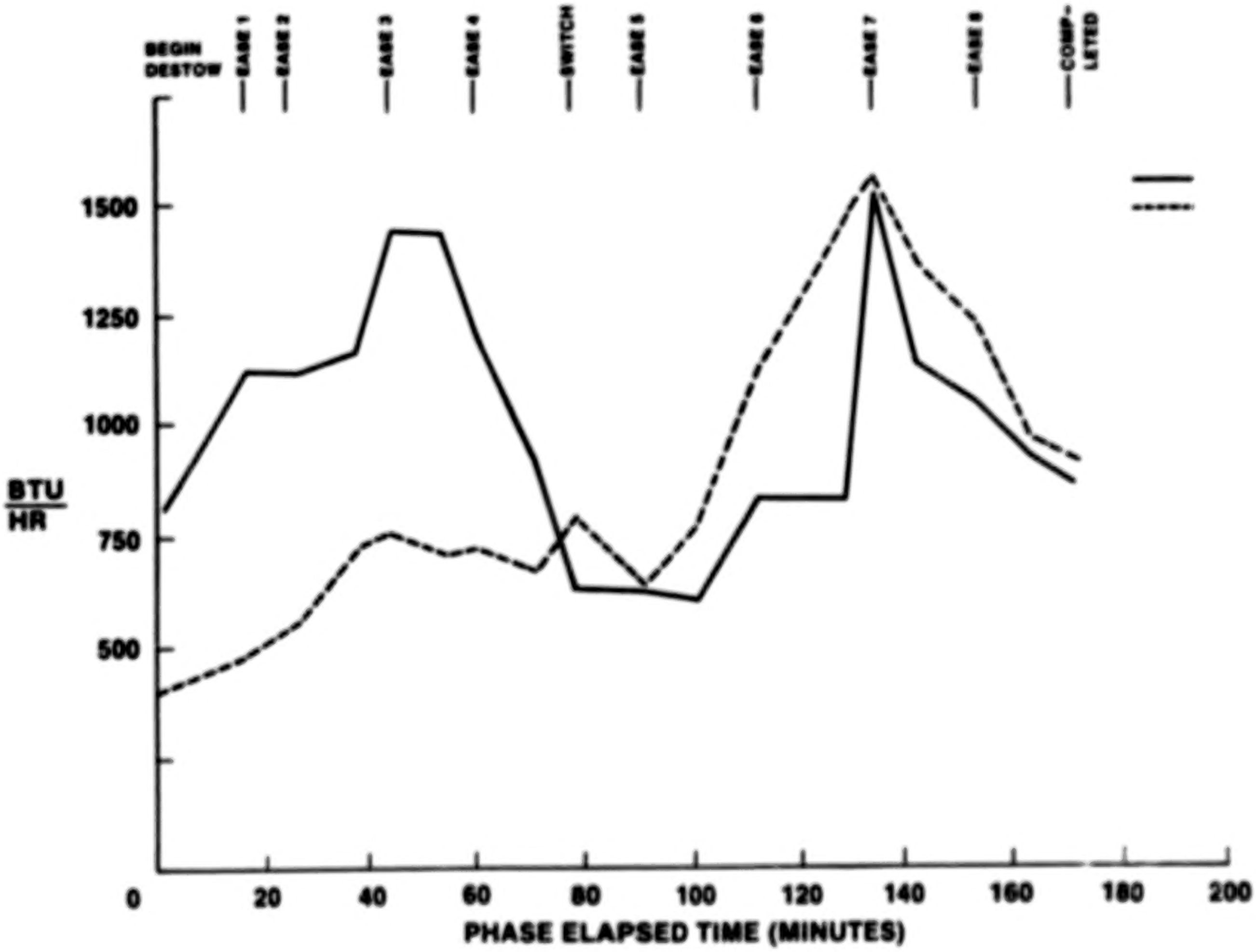

Figure 3

FLIGHT 61-B EASE/ACCESS AVERAGE ENERGY EXPENDITURES

Although metabolic rates are often described as if they were a precise function of a given work task, the variation among individuals reminds us that total metabolism is a function of body mass as well. When the differences in total body energy output during the Flight 61-B EVAs are corrected for body weight, the rates are almost identical for the 2 crewmembers. Table I shows the computations in terms of BTU/Hr and also BTU/Hr/Lb for both EVAs broken down into the ACCESS and EASE phases. The mean metabolic rates are similar in the EASE and ACCESS phases, although the peak metabolic rates during the EASE phase are higher (Fig. 3).

FIRST EVA (61-B) METABOLIC RATES

ACTIVITY	CREWMEMBER (BTU/HR)		CREWMEMBER (BTU/HR/LB)	
	EV 1	EV 2	EV 1	EV 2
ACCESS	1144	892	6.0	6.5
EASE	1084	869	5.7	6.3

SECOND EVA (61-B) METABOLIC RATES

ACTIVITY	CREWMEMBER (BTU/HR)		CREWMEMBER (BTU/HR/LB)	
	EV 1	EV 2	EV 1	EV 2
ACCESS	924	680	4.8	4.9
REMAINDER OF EVA	916	672	4.8	4.9

Figure 4

PROBABILITY DENSITY PLOTS FOR APOLLO, SKYLABS, AND SHUTTLE METABOLIC RATE DISTRIBUTIONS

These plots, Figure 5, based on estimated means and standard deviations illustrate the spread and central tendency of each of the three sets of average EVA metabolic rate measurement, i.e., Apollo, Skylab and Shuttle. The average metabolic rate during the Apollo EVAs was 235 Kcal/Hr (940 BTU/Hr) and the Skylab EVAs averaged 238 Kcal/Hr (952 BTU/Hr). The average metabolic rate during Shuttle EVAs was somewhat lower at 197 Kcal/Hr (788 BTU/Hr). Although the mean of the Shuttle data is significantly lower than that of previous programs, a wide variation in energy requirement exists, depending on the nature of the EVA task.

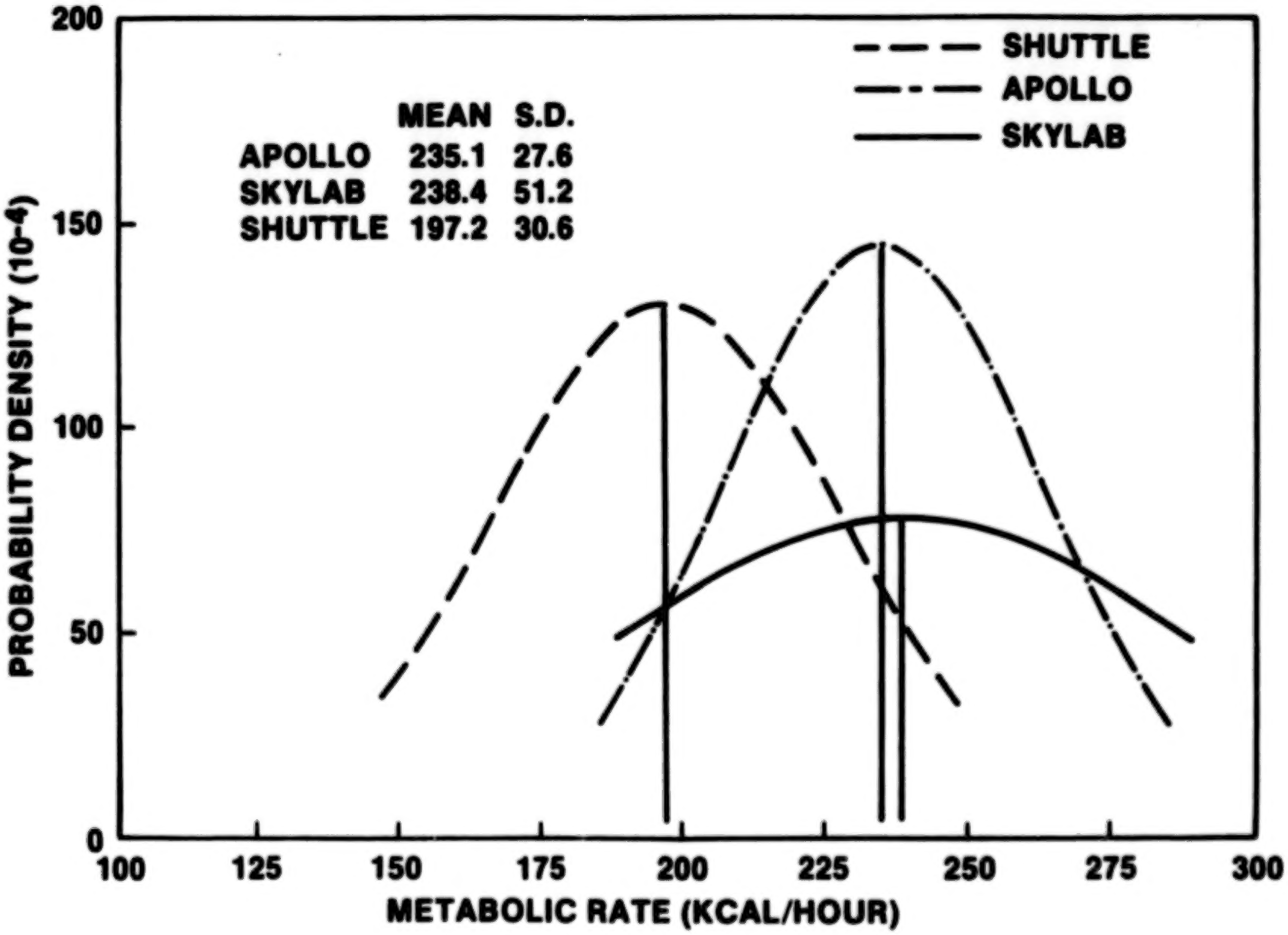

Figure 5

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PANEL DISCUSSION
RESULTS OF FLIGHT DEMONSTRATION

GEORGE LEVIN:

Let me make some opening comments before we get started into the panel discussion. Participating in this panel discussion are Dr. Mary L. Cleave, RMS operator for the EASE/ACCESS experiments on STS Flight 61B, Lt. Col. Jerry L. Ross, EVA crewman for the EASE/ACCESS experiments on STS Flight 61B, Walter L. Heard, Jr., principal investigator for the ACCESS experiment, Dr. David L. Akin, principal investigator for the EASE experiment, and Charles E. Whitsett, special assistant for payloads. I would like to ask Ed Whitsett if there's anything that he would like to add since he's not had a chance to speak previously.

ED WHITSETT:

Well I'll just make one remark as far as the Space Station is concerned. As you may be aware, we are working on some suit improvements, but the initial assembly is going to be done with the Shuttle system, because obviously the Space Station is not operational until the crew is on board, and so what you saw in the EASE/ACCESS system is essentially the suit system that will be available for the early Space Station assembly.

QUESTION:

I'd like to address this to either Professor Akin or to the crew. Based upon the assembly problems or lack of problems that may have been encountered, are there any modifications that you have proposed with respect to truss assembly, beam assembly for the Space Station Project?

ANSWER, DAVE AKIN:

Well let me say that we never made any claims that our truss looked anything like a space program truss. It was intended to be a structural assembly experiment, but what we were looking at was the crew, not the structure. So I think that, in terms of Space Station, Doug is probably a better person to talk to on what the Space Station structure should look like than I would be.

DOUG HEARD:

I think that what you're ultimately going to see for a Space Station, and essentially what is baselined right now is a merge between ACCESS and EASE. We'll be using components that are much more the EASE size, but we'll be using a process which is much more akin to what ACCESS provided.

MARY CLEAVE:

When it comes to the arm, we need to get the construction further back and away from the limits of the arm, and also we need better lighting like some kind of running lights, but other than that, it worked real well.

QUESTION:

Jerry, in light of recent Shuttle developments, what do you believe to be the future of space construction?

ANSWER, JERRY ROSS:

I don't see any difference. Obviously we're not going to fly for a while. We may not have as many experiments under our belts in the time frame we'd hoped for, but I don't see any delays in the Space Station program. We're pressing on. We're still proceeding through Phase B, and about to enter into C/D phase Space Station and hopefully we will be able to put our structure up in space in early to mid 1990's.

QUESTION:

What do you foresee as, and Dr. Cleave, if you would answer this one, what do you see as the future purpose, would it be a realistically successful one, and if it will be, by what year?

ANSWER, MARY CLEAVE:

I see the purpose of the Space Station in and of itself being a orbiting laboratory which will open up a lot of opportunities hopefully for basic scientific research. There are a lot of material science questions and opportunities that are available and also a lot of just general experiments that we need to do in order to better understand how to better utilize space without specific applications in mind. Hopefully people will be able to use their imaginations.

QUESTION:

Just this question to the crew. When you used the remote manipulator system (RMS) to position yourselves to do the construction, did you find that reduced the amount of time to do the construction or complete it, and was that a great tool to aid you in the construction process?

ANSWER, JERRY ROSS:

Let me start. I think in probably most respects, because of the hardware that we're dealing with, the RMS probably caused us to take longer in assembling the hardware. But from an ease standpoint, at least from the people out on the extravehicular activity (EVA), the fatigue factor went way down. You were using your feet to restrain yourself, and you're using RMS to translate around. All you had to use your hands for was the actual task of doing the assembly. That certainly was a very desirable way to do business.

I think Doug and the guys that designed ACCESS, designed it to be constructed from a foot restraint, not from the manipulator foot restraint (MFR). It worked very well as it was designed to do. The MFR was just an extra thing to see if you could fix it if it broke or something.

DOUG HEARD:

I would like to say something about that too. For the Space Station, the hardware is much longer and much bigger, to cut down the number of pieces that we have to assemble. There's some rest time - some ride time between nodes for the astronauts to rest some. However, with ACCESS, one man is working 100% of the time. There really were no periods of idleness when he could rest a little, but in working with the Space Station and that size structure, there will be some of that time in there.

QUESTION:

We have read quite a lot about motion sickness, many of the astronauts are being subjected to it or feeling it in at least some part. Did you have any motion sickness at any time during the construction phase or before, or was it a factor in any way?

ANSWER, JERRY ROSS:

Well let me first of all say it's not motion sickness. It's something we don't fully understand yet. It is akin to motion sickness in some of the symptoms. I personally did not have any problems. I had a great time the entire time I was up there and I'm thankful for that. Some of the crew did have some minor problems, and it's about on the same ratio as we've had in the past. It has never stopped any crew member from doing their job if they had something to do. We might in some cases, depending on criticality of certain tasks, schedule a certain task later in the mission when we're more or less certain that the entire crew should be "up to snuff" and be ready to do those things. In particular, we recommend in the Astronaut Office, and we try to schedule it that way, that we never do an EVA before flight day four if possible, just to make sure the entire crew is up and ready to respond to the activities. Outside there on the EVA's, both of them, Woody Spring and I felt perfectly fine, had no feeling of falling or anything like that. The only time that I even had a minor loss of reference, I would say was when I was coming back down, taking the cable down. It wasn't uncomfortable, it was just - I was kind of giggling to myself, saying okay, I know I feel this way, but it doesn't make any sense.

QUESTION:

I had one other question. I think Dr. Akin mentioned the fact that this experiment, as I understood it, took you to your limit. Maybe I'm overstating that, but you had a good task to do. Did you feel that this activity basically was taking you to your limits of doing what you were doing?

ANSWER, JERRY ROSS:

Well at the point where we had completed four builds of EASE, the ground asked us if we would continue on with Woody on the top for two more builds of EASE. Woody didn't want any part of that, and I wasn't certain that I wanted to do that and then go build two or three more from the top myself. So we opted to swap at the point we'd planned and to see how we felt at the end of six. I felt comfortable with attempting to do two more times, and so did Woody, and that's what we completed. At that point, we decided that it was time to come in because we were both pretty well exhausted.

QUESTION:

One other thing, it was difficult for us to see the degree to which you were communicating verbally. I presume you had good communication, like talking to one another.

ANSWER, JERRY ROSS:

Yeah. We kept up a pretty good chatter, just like you can imagine doing any kind of a job around the house with a partner or any type of construction task. You know, if you need a wrench, you holler at him, if you hand him a beam and he doesn't see it, you tell him.

QUESTION:

I'll address this one to the crew. Recently, the question of whether the Space Station structure should be deployable or erectable is being revisited some. Based on the experience that you've had in the EASE, are you ready to build the Space Station via construction, would you like to have it be a mixture of deployable or erectable, or how would you like to do that?

ANSWER, JERRY ROSS:

We're ready to go or do whatever the agency decides is the right thing to do. I wasn't aware that we were trying to decide whether it was to be erectable or deployable, but there's obviously advantages to both. Hopefully when we come out with the final design, we'll use to the best advantage each capability wherever it makes sense.

QUESTION:

All the comments on work have been in terms of orienting your body and carrying the big strut members that we would envision for Space Station. Also, whenever you hook up a node, there would be some quality checks, instruments that needed to be connected, and small tactile tasks after your long stay out there. Do you think that your ability to do these small intricate tasks would inhibit you from doing too much out there?

ANSWER, JERRY ROSS:

Certainly as you get tired, your capability to do small motor skills is probably going to be degraded somewhat. Hopefully you design the task such that it makes it fairly easy to be done. If you're trying to make electrical connections, you recess the pins such as you mate before you get any pin contact so that you don't bend or break them. If you can, if you've got a lot of connectors on a box, you gang them all together on one big connector so that you only have one process to do. I think that you can do a lot of things design wise - access, reach, tools required, types of tasks required and forces required that will make things easy, so that hopefully you won't start having a fatigue problem. But certainly, hopefully, the crew will be smart enough to recognize they're getting to the fatigued point where they don't want to work anymore. It's probably not smart for them to be out there from a safety standpoint as well, so they better get back inside. That's one thing about Station, you can go back out again tomorrow, or your buddies can go out again tomorrow.

ED WHITSETT:

I might add parenthetically that that is a part of the activities we've got on-going now. The development of what we call "scoop proof" connectors, where you can't bend the pins. The connector is sized so that it fits comfortably in the hand of the astronauts, reducing the workload and fatigue they'll be experiencing when they have to put the electrical connectors in.

QUESTION:

This question has already been alluded to a number of times, but I'm going to try to ask it a little more directly. Recently, Gordon Fullerton issued a report in which he recommended reduced EVA time for assembly of the Space Station. You made a comment earlier during your presentation, that you felt you could build a structure in an efficient manner, given proper access to the material. My question really is what alternative methods to the assembly or additional aids do you see - in particular, would you be interested in a telerobot or teleoperator, either at the end of the remote manipulator system (RMS), on the MFR, or someplace like that to assist you in the assembly of the Space Station?

ANSWER, JERRY ROSS:

That's a toughy. Let me first of all address the background that you gave there. Gordo's memo that he put out and put through the management echelon at Johnson Space Center (JSC) was addressing some concerns he saw as to exactly where we are now, where we plan to go, and some things that he thought may eventually be showstoppers. Just one of those was EVA, and a very small part of the EVA concern was the actual assembly process of the Station. A much larger driving concern of the EVA was the very large number of hours that was being projected for EVA requirements to maintain the Station once it's there and in being. And that says if you have a six person space station, you might require a major percentage of that time just to try to keep the shop running, and is that the best way to do business. As far as constructing the Space Station from the Shuttle, initial indications of what we've seen, says that you're going to require at least four and maybe five Shuttle missions just to bring up and assemble the hardware for the large structural portion of the Station. Then we get the same input from the Space Shuttle Program Office that says, Space Station, you can probably count on three missions per year to build the Space Station. When you add those together, you realize very rapidly that there's no way you're going to get that Space Station up

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there and assembled in a reasonable fashion before you're starting to have logistics to repair and resupply the things that you've already got up there and are trying to maintain. And it kind of looks like you might get into a no win situation. Those are the kinds of concerns that Gordo was expressing. I don't think that we in the Office have concerns about the fact that you can in fact go out and assemble a space station given the proper types of tools to do that. The question is the timing, the capabilities, the number of flights available, and the time period that you want to do that. As far as telerobotics goes, I'm not an expert in it. I really don't have a good feel for it. My initial cut at it from what I've seen is that a man outside EVA can be much more productive than one or two people sitting inside trying to do things remotely, watching TV screens and operating some mechanical systems from inside the Shuttle. You can spend long hours inside, trying to do what two guys can do outside in a relatively short period of time.

QUESTION:

What if you had a teleoperator, maybe to help you get the material? Do you see that as being of assistance?

ANSWER, JERRY ROSS:

Well we expect that we will have at least the Shuttle arm to be able to manipulate structures as we assemble them, to provide hardware, or to position the crewmen, depending upon what scenario and what type of assembly fixture you use to construct the Station.

QUESTION:

Mary, do you have any comment, being the RMS operator - the nearest thing we have to a teleoperator?

ANSWER, MARY CLEAVE:

Well, I think that having the RMS is a great tool, and it's going to help a lot in Space Station construction. But there's a lot of crew coordination and training that has to go on, and as for your definition of teleoperator, I'm not really that sure what you mean, so I can't really answer that question too directly.

QUESTION:

I'd like to address this to Jerry, just a quick question. Today we mentioned the thermal temperature difference on the struts which could be almost up to 400F from one side to the other. Was that sensed through the gloves at any time when you were maneuvering the struts?

ANSWER, JERRY ROSS:

No. I never really noticed a hot surface that I was touching. I did notice some cooling tendencies in the suit, especially in the legs, lower back and the hands whenever we went from a sunlit condition to a dark condition, whenever we got high above the cargo bay on the RMS, or whenever we went outboard from the cargo bay and were essentially over the radiators as we were translating up and down the sills a couple times. But I never felt anything that felt hot, or I never felt anything that felt uncomfortably cold.

DAVE AKIN:

I think that the 400F number comes from the allowable temperature difference between differential sections of EASE; there were no thermal sensors on the hardware, but the thermal sensors from nearby portions of the payload bay were reading right around 0C for most of the EVA.

DOUG HEARD:

We were probably in what would be considered the most comfortable thermal environment with the cargo bay towards the Earth essentially during the entire EVA.

QUESTION:

Jerry, I have another question. You were stressing your extravehicular mobility unit (EMU) boots very highly in some of your movements as the low man on the EASE. When you came back in did you check your boots, and did the suit people check your boots post flight to see if there were any wear conditions that might have occurred due to that.

ANSWER, JERRY ROSS:

I counted them. There were two of them so I decided it was okay. I had some concerns about that because Woody was doing this very thing in the water tank. I asked the suit people if they had any concerns about that; they looked at it and decided that it probably wasn't a concern. I don't know if they looked at the suits after. They normally tear the suits apart and look at every piece part. But we never heard anything back that they had any concerns or saw any damage, so I don't think we hurt anything.

I might mention that earlier on the reset repair mission 51I, Ox VanHoften was grabbing hold of a 14,000 - 15,000 pound satellite. The boot interface was examined very carefully there in case he grabbed hold of the satellite while moving. The question came up, could you pull the boot loose or something like that. The margins were very high there, and I'm sure that by the time 61B came along, they weren't real concerned about it.

QUESTION:

I wanted to ask the two astronauts what they are doing to keep themselves busy.

ANSWER, MARY CLEAVE:

Our work schedules are really loaded with a lot of safety reviews. Right now for example, I am working all the downstream RMS, Ford and RCA satellites, all the mid-deck experiments and half the payload bay pallet experiments. We're going back over everything, and viewing it for safety concerns and on a whole having more time to try to integrate it to optimize these experiments. Everybody's real busy.

QUESTION:
How do you cope with delays, depression over not getting anywhere?

ANSWER, JERRY ROSS:
Get mad. Doesn't do any good. You've got a bunch of very energetic folks down there that very much want to go fly in space - that's what they were hired on for, and that's what they're trained for. They're darn proud of that and they want to get at it again, but nobody wants to go and do it until we get things right. We've got a lot of folks down there who are working on various different commissions and processes getting things right. I'm not working on any of the Shuttle accident activities. I'm working on Space Station right now - primarily concerned with EVA, maintenance and the mobile manipulator that we have on board. I'm also working on some space servicing activities. It's a joint Department of Defense (DoD)/NASA study. I am also still assigned to a crew, and still training at least on maintenance level to not lose the level of proficiency that I have at this point. Everybody is staying gainfully employed. We are still flying. We're going to symposiums like this. We still have our public relations that we do, and we're just trying to stay ready for them to get a Shuttle ready, and we'll be ready to go fly again.

QUESTION:
This is for Dave AkIn. The next to the last bullet on one of your charts, you mentioned that most of the work came from the suit. What do you base that on?

ANSWER, DAVE AKIN:
As I was saying, things were getting a little hectic toward the end (of the talk), but by going back through the motion reconstruction, we can deduce the energy applied into the motion of the crewman's body, and the motion of the hardware. In doing that process, we can only account for about, in all cases, less than ten percent of the metabolic rates that were coming back from the instrumentation. As you heard, another third to one half can be accounted for by basal metabolic rate. So there's about 500 BTU's per hour unaccounted for. The only two sources for that are isostatic motions - for example, if I take my two hands and push against myself, I'm expending energy, but I'm doing no work - and actually work against a suit. In most cases, there weren't enough closed loop motions - you have to have a closed loop in order to have these isostatic forces. Most of the time, that didn't exist, so the only other possible answer is the suit. All I can say is that there really are 500 BTU per hour unaccounted for, and in some cases, these can be the kind of forces that don't give rise to motion, so that we can't analyze it externally. The conclusion is that certainly the suit is accountable for a large fraction of that.

QUESTION:

Jerry, can you, from a subjective standpoint, talk about that? Do you notice that?

ANSWER, JERRY ROSS:

I think 450 of that 500 BTU's is right here (pointing at wrist). Hands and forearms get really tired; you're walking, you're working, you're doing everything with your hands so you can expect that to be the case. A lot of times, you are actually trying to react against your body. When you're moving a beam with one hand, you're applying an opposite torque with the other hand to hold yourself in position. I'm not sure that's accounted for, but it's an equal amount of work on both sides as you're going to torque yourself around. So maybe some of the numbers you have, Dave, could be multiplied by two.

QUESTION:

This question is addressed to Dr. Cleave and anybody else who would like to comment on it. In the Space Station in the future, you mentioned downstream RMS requirements. In the future, do you see a lot of problems with the collision avoidance? In use of the RMS, whose going to keep track of all of these large structures floating around? Is it going to be mission controllers and the astronauts or is it going to be people worrying with software, singularities and collision avoidance?

ANSWER, MARY CLEAVE:

That's a real good question. I know just with the RMS as we have it now, we were going to have collision avoidance software, but we ran out of room. I can't see that there aren't 50 million people always competing for a little bit of computer space. That might not always be the case, or it might be desirable to have collision avoidance, but you're going to end up relying on an operator to make that not happen, and that's what we get trained for. As for whose going to be responsible for when we're up on orbit, we're ultimately responsible to make sure that we get whatever we're operating back in one piece. So it always ends up being us in the long run I guess.

I think on the Station, it's also going to be a combination of software protections as well as crew operations. But obviously that dictates that you give the crew visibility into wherever there going to have to operate that arm, and you start talking about football field type areas, that makes the task pretty tough.

QUESTION:

Could someone explain why the Space Station has to be at 14.7 psi? A related question having to do with EVA's and the operating pressure of the suits is why can't we use some sort of different gases - inert gases to take the nitrogen out?

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ANSWER, JERRY ROSS:

Well let me try to address it as far as I understand it, and I don't claim to be an expert. It's my understanding from the answers I've got asking the same question, that the 14.7 is essentially a standard atmospheric type mixture of gases and is required by life science experiments, so that they can do a one-on-one comparison against their ground baseline data. Now I asked the question, "Do you guys accept data from the University of Denver or the University of Mexico in Mexico City?", and the answer has always been, as far as I know, yes. I said, "Well, what is the partial pressure of oxygen at that university, and what is the total pressure at that university?"; they tell me, and as far as they're concerned, that's the end of the discussion. It doesn't make any difference to them. I don't understand why we can't go to a 10.2 psi cabin from a structure standpoint. It sure would make a lot more sense from an EVA standpoint - it makes it much easier to operate, especially in the pre-breathe requirements and the capabilities that you could have. The suit technology does not have to be expanded significantly, in some areas anyhow, beyond what we have now. Whether you still have to be enhanced from a maintainability and capability standpoint on orbit, I've never been able to find the exact person that said by golly that's the way we're going to go, and that's the way it has to be, and this is why. But I've asked the question quite a few times. That's my understanding of it, and I hope that helps you some. Maybe Dave Horrigan can expand on what I just said.

DAVE HORRIGAN

As far as the 14.7 cabin is concerned, from the point of view of decompression, you don't have to have a 14.7 cabin. What you have to have is a way of getting from point A to point B. In other words, if you have a sea level cabin and a 4.3 psi suit, then you're going to have to wash the nitrogen out of the body over time. That can be done either by decreasing the cabin pressure to like 10.2 or 8 for a period of hours - 12-24 hours, and then going out to whatever suit that they have available. If it's a given that you have to have a 14.7 cabin, and you want to go out immediately without this long interim of time, then you have to have a suit of higher pressure, a no pre-breath suit so to speak, which would be 8 or 9 psi with all of the associated engineering problems as far as the development of the gloves is concerned. I think that the original question had something in it about using other gases such as helium, and that's been used in diving. It can shorten the pre-breathe time, but you still have to pre-breathe to get the helium out. You have to take the time to replace the body's nitrogen with helium, plus you have the problem of the whole crew being exposed to a different environment. With regard to a sea level cabin requirement, recently Dr. Kerwin took the position that you don't have to have a sea level cabin for life science experiments. You could have it up to 4,000 feet or so, since, as Jerry well pointed out, a lot of research is going on at different altitudes. However, there's a great deal of pressure, I think from many factors - those who were developing various systems, not necessarily biological experiments, that would like to keep a sea level cabin, so there are lot's of options. You can have a sea level cabin and a 9 psi suit or you can have an interim pressure drop of the cabin down to 10 or below and have a lower pressure suit, this is a value judgement that has to be made, and there are a lot of complicating factors involved in it. The problem is if we stay with a 14.7 cabin in our 4.3 suit, we'd have to pre-breathe the suit for 5 hours and 45 minutes or so.

That's right. To do a straight pre-breathe, it would have to be in excess of 5 hours to get down there, and that's just an unacceptably long time to be constrained in pre-breathing oxygen and doing nothing else.

QUESTION:

While you had the big truss up, did you give it a rap or some kind of a bang? Can you tell us something about the structural character of it out there that may be a little different?

ANSWER, JERRY ROSS:

At one point, as I was removing one of the clips that held the simulator electrical line along the side of the ACCESS truss, I pulled one off without supporting the truss with my other hand; when it popped off it gave the entire truss and the assembly fixture a pretty good twang. I think some of the engineers at Marshall tried to do some natural vibration work with that data, but I'm sure that almost all of the oscillation was due to the assembly fixture and very little, if any, to the truss. It was a very stiff structure.

QUESTION:

If you take a first order special theory space orbit it would be what happens in the tank is what happens in orbit. I think that's what Colonel Ross said.

ANSWER, JERRY ROSS:

Let me see if I understand your question. You're saying what we observe in the tank is essentially what we can expect on orbit? On EVA?

QUESTION:

Yeah. In terms of how long it takes to do a procedure?

ANSWER, JERRY ROSS:

Relatively. We do use a slight bit of windage when we're laying out a mission and planning for it. Call it conservatism or whatever you want to but we do use a little bit of windage accounting for the knowns of the zero G versus the damping of water, etc.

QUESTION:

Before you can get, for example, an operations maintenance manual for a space station, you have to back that up in tanks.

ANSWER, JERRY ROSS:

That is our hope.

QUESTION:

And you'll need to have something close to your unified theory before you can be reasonably sure that validation in the tank will work on the Space Station.

ANSWER, JERRY ROSS:

For any sub-task we can simulate in the tank, we'll be happy if we can validate the sub-task in the tank on realistic type hardware. You don't have to translate three hundred feet over a piece of structure to tell you how long it's going to take you to translate three hundred feet - you can translate thirty feet and extrapolate. But we do not have facilities right now that we can put large structures (even a space telescope) into, and do a reasonable end-to-end task.

QUESTION:

Are there plans to have lots more tanks? Prior to the Space Station? Because it seems to me that you're going to have a lot of operations and maintenance procedures, a lot of them that have to be validated before you can send anybody up after construction.

ANSWER, JERRY ROSS:

I agree with that. I think Marshall was looking at possibly building a newer or different tank anyhow. JSC at this point is not. In our postflight debriefing, I raised that flag to our management, our training people, as well as the Space Station people; it's not accounted for in any budget and not currently planned.

QUESTION:

My question is to Jerry. I believe, if I'm quoting you correctly, both you and Woody Spring started working out with weights about two months prior to the mission. In terms of reducing fatigue during the actual mission, do you think any type of exercise protocol, for example, from the first day up to the time of the first EVA, might reduce the amount of fatigue during the first EVA and do you think that subsequent EVA's might be influenced by the same exercise protocol?

ANSWER, JERRY ROSS:

I think that probably would depend on the individual and his whole body make-up. I find that if I don't exercise for three or four days after I've put in a good work out, I'll probably be in better shape and can run farther or do more weights or whatever than if I had exercised every day for the four days preceding. I don't think that was an influence at all on the first EVA. Our adrenalin flow was pretty high and we didn't really notice we were tired until we stopped and thought about it a little bit, towards the end when we really started dragging a little. The second EVA, I think the best way to get ready for it was to have done the first one and had a day of rest in between. When I do exercise, I normally will run one day and lift weights the next and then run the next day and lift weights the next, and that's essentially exactly the way we did it on the EVA. We really felt like we'd had a good workout and it was refreshing to have done some good hard physical work after your body gets lazy in zero G, but at the same time a day in between was nice.

QUESTION:

In the tank, when you are going from, for example, the top to the bottom, you have a large variation in the water pressure, 33 feet I believe is one atmosphere. Did you notice any substantial difference in the ability to work in the suit from the top to the bottom at that range of pressure?

ANSWER, JERRY ROSS:

No, we have a pressure regulating system that controls the delta P across the suit to the same pressure. Now you do notice some difference in the suit from the head to the feet, depending on whether or not you are working upside down or right side up. That is because you do have a two to three foot delta in pressure, and that's a half psi per foot I think, so you can notice it. Sometimes, if you're working upside down, you'll actually be working at your hands at a delta P across the suit exceeding 5 psi and you can sometimes tell the difference.

QUESTION:

That system is pretty fast and you're saying, in other words, if you start from the bottom and kick yourself off, that pressure equalization is faster than you're moving?

ANSWER, JERRY ROSS:

Yeah, we try not to do that. It hurts sometimes.

ANSWER, MARY CLEAVE:

Yeah, on the arm, in the Marshall tank, there were times when these guys would start floating away and you could tell exactly when the pressure valve relieved, cause they'd stop floating away.

QUESITON:

Are there any plans in the future assembly flights to have the astronauts possibly temporarily trussed while they are assembling the structure. This could be compared to a person washing windows on a sky-scraper and is trussed up to the beams to reduce movement but allow more security as the work is being performed. Has that been proposed in any way? Would that be advantageous?

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ANSWER, DOUG HEARD:

We do have some plans to do some more work with Space Station sized structure, the five meter and the seven meter beams - we have some. You'll hear about the SAVE experiment this afternoon. We have some hardware being built now to be sent to JSC, probably this month, that they will work with down there. There is a mobile work station approach. We try to use the astronaut's brains, eyes and hands to do the work. We like to use a machine to move him around and there is some work planned.

QUESTION:

One of the things we worry about in Space Station is meteor impact and debris impact. You were out there for six hours or so; did you see anything, anything fly by?

ANSWER, JERRY ROSS:

No. From inside, every once in a while, we would see something going by the Orbiter, but I'm quite confident that it was something from the Orbiter. We'd see little washers floating off, especially when we opened the cargo bay doors the first time - there's a lot of stuff coming out there. I know the Cape does a darn good job of trying to keep things clean, but there's still a lot of things that come floating free. We had a lot of ice that comes off of nozzles and engines and things and will fly formation with you for long periods of time. But if anything came by, it didn't hit us number one, and number two, it went by so fast we didn't see it.

QUESTION:

Jerry, would you relate the mobility that's needed for something like the Space Station, which is a block long, and 35 stories high. Could you address the use of a man maneuvering unit (MMU) for mobility as opposed to a RMS type for going to specific points for maintenance or observation?

ANSWER, JERRY ROSS:

Ok, that's one of the harder questions of EVA in a space station I think - but let me try. The current mobile servicing station concept, or the moveable RMS platform, moves at such a slow rate that you would never want to have an EVA crewman get on it to be transported from A to B. He'd spend half of his time getting there and the remaining half of his EVA time coming back. The MMU is not currently baseline for Station, at least at inital operating capability (IOC). The MMU has advantages for going from A to B, but there are other penalties. Those penalties are: 1)the overhead of getting into it, 2)the propellant, nitrogen gas or whatever,is expendable, and 3)once you get there, you really don't want to work while you are in the MMU, so you have to have some way of doffing, stowing or berthing the MMU so that it's not in your way while you are trying to do a task. That is not to say it doesn't have advantages in certain instances. I think we in the Astronaut Office would certainly like to have an MMU on board the Station at IOC and if not then, as soon thereafter as possible. I think probably the best answer for translating around the Station will probably come on some kind of a subway rail system for lack of better words, where along the cable trays or something on the inside of your square truss structure, you've got a track with some kind of a dolly mechanism. You can attach black boxes, hardware, tools, whatever it is, and a crewman can use it kind of like an elevator, if you will, and transport himself around. If you design things properly, he can tether himself to that such that he doesn't have to have slidewires or whatever running over the entire Station. Once he gets to his work station, he can remain tethered to that dolly system, go off and do his task, and return, and not have a lot of encumbrances around the Station to support: handrails, slide wires, all that type of thing. That, to me at this point, is the most interesting and probably the most promising concept of transporting around the Station EVA.

QUESTION:

I'd like to direct this to the astronauts. Would you please comment on your personal feelings in zero gravity, since here on Earth if you stand on your head, it doesn't take long for the blood that rushes to your head to make you very uncomfortable. Certain parts of your body probably float around; do you feel like your stomach goes up around your diaphragm or something?

ANSWER, MARY CLEAVE:

I didn't have any sensation of having any of my internal organs going anyplace they weren't supposed to be. Some people have said they did. I didn't have any trouble with back aches; some people when their spine separates, all those little muscles in the back cramp up. What I did have was, after fighting pounds all my life, a wonderful sensation that I didn't weigh anything. And probably, it was real depressing for me when we finally got in after entry to understand that I had just gained a hundred pounds in less than an hour. And lost an inch.

JERRY ROSS:

My initial sensation at main engine cutoff, or the first point that we sensed zero G - it's an instanteous transition from plus 3 G's pushing you back in your seat to zero G's and that transition gave me a tumbling sensation - I felt like I was tumbling head over heels. It wasn't all that uncomfortable, it was just a sensation that was there and I ignored it as best as I could. I had responsibilities to get out of my seat and start throwing switches fairly shortly after we got on to orbit. As soon as I got unstrapped from the seat and I lost those sensory ques of being pressed into a seat, that tumbling sensation went away and I felt great from then on - I felt like a hamster in a cage. And it was great. Zero G was the best thing ever invented.

MARY CLEAVE:

He was more like a bull in a china shop, but we won't talk about that.

JERRY ROSS:

We won't tell you that Mary's nickname is now 'oops' Cleave. Should have been ricochet. But I had lower back pain from the fact that my spine was straightening out and I think also the distance between the vertabrae was expanding a little bit. It was stretching the ligaments, tendons, whatever they are, I'm not sure, but it hurt anyhow. It wasn't something that bothered you a whole lot in the day when you were working, but at night when you tried to go to sleep, it was a low dull pain that was there all the time. That was ok, because I didn't want to sleep anyhow, there were too many neat things to look at out the windows. I had a full head sensation, essentially throughout the entire flight and that's due to fluid shift from the lower torso up to the upper half of the body. Your body tends to want to get rid of a lot of that "excess liquid" over the first several hours on orbit, so there was a line at the head several times. And, by the way, we have to rehydrate ourselves before we come back in to counteract any adverse problems in reencountering G. I had a stuffy head feeling the last couple of days on orbit and I liken that to the fact that the cabin air was starting to get rather dirty. But other than that, zero G was great. I had some weird sensations when I got back on the ground, I felt light, everybody else felt heavy, I felt light. I felt like I had a spring in my step, I felt like I was almost floating in the bed when I slept at night. The only thing I can attribute that to is that all my touch sensors had been detuned during the seven days up there and so even though I was lying there and putting the same amount of pressure on those sensors, they weren't sending out the same signal to the sensory system. Therefore it felt like for at least two nights after I got back on the ground that I was almost floating right on top of the bed when I was sleeping.

MARY CLEAVE:

I felt like I was running around with a 100 pound backpack for the first two days.

JERRY ROSS:

I think something that helped me was I stood up for a good share of the re-entry. I acclimated very rapidly and it was no big deal, especially carrying around a forty pound camera. At 1.5 Gs, I stood up and did some deep knee bends on re-entry and that again was no problem.

QUESTION:

On the cold hands, Jerry, you mentioned that it was partly the environment, that you noticed in the sun they were warm and in the shade they were cold. Did you associate perspiration or metabolic rate with the discomfort in the hands? Or was it discomfort?

ANSWER, JERRY ROSS:

Yeah, let me set something straight, somebody wrote a memo that we complained about very cold hands. We did not complain about cold hands. We had comfortable temperatures throughout the suit during both EVAs. We did sense whenever we slowed down our activities, whenever it went from sunlight to night, whenever we went up high into the bay on the arm or when we were outside of the bay, we did notice a cooling tendency - that was it. Sometimes it would go to the extent that we would turn down or up, whichever you want, getting less cooling out of our suit system, but we never got cold. Some crews have gotten kind of cold because they didn't do anything for long periods of time except sit there and hold a satellite high above the bay. We did sense moisture in the suit and we commented on that. We'd been asked to preflight and we tried to give a fairly thorough commentary on comfort, cooling or hot tendencies as well as moisture in suit. And if you look at the transcripts of the tapes, we rather routinely gave accounts of that and I think, if you read them, you'll see that they were in fact there but they weren't a big deal. The suit has more cooling capability than is required in my opinion.

QUESTION:

After being shoehorned into a suit for eight hours that you have described as a little bit too small, did the back pain diminish at all?

ANSWER, JERRY ROSS:

That's interesting, I should have said something about that. Once I got into the suit and got clamped in there, and the first time by the way was a really tight fit, the second time was much easier to get into, the back pain went away. That's because it was recompressing the spine and putting the curvature back in and everything felt good. I felt good until I tried to go to sleep that night and I had the most severe back pain of the entire mission that night after the first EVA; it was to the point that I was looking for Tylenol. They didn't help a whole lot. But again, it was just one of those things that you had to put up with. After the second EVA, I no longer had any more back pain and I didn't have any for the rest of the flight. The body is pretty adaptable and it doesn't take it too long to adapt.

QUESTION:

About the hardware, you seem to handle it very well, but do you have some feel for sensitive hardware. If we designed something to have a type of sensor in the suit out there as to how much force you are putting on something?

ANSWER, JERRY ROSS:

Yeah, we have a reasonable feel for what kind of force we are putting on things as long as you are talking about the forces we're putting on the structure through our hands. If you are talking about through our feet, reacting through a foot restraint, moving a beam across part of your body or cradling it in your elbow and pushing it like that, it is much harder to evaluate the forces that are being put in. You know, I anticipate that whatever type of structural materials we use to build a space station, there are going to be coatings or coverings or just the flat material itself that are going to cause concerns about being dinged, scratched or whatever. I think we can probably handle those satisfactorily as long as we have a good means of restraining the crewmen, presenting the work material to them and moving to the work positions to do the assembly.

QUESTION, DAVE AKIN:

I have a question. There is some mention in the talk on biomedical results about some studies, repetitive one day EVAs: going out for three hours, coming in for lunch and going back out. Do you think you would have preferred that to the way you did it?

ANSWER, JERRY ROSS:

No. I don't eat lunch number one, and number two, for the overhead of getting in and out of the hatch, tethering, untethering, getting in and out of the suit, the whole nine yards, a six hour EVA, I think is, about the right duration, I don't think you would want to do much more than that, even if the suit capability provided it unless it was a lower level of activity kind of thing. But I think seven or eight hours in a suit in one day is plenty.

QUESTION:

Does the suit have a waste collection system and the other thing, do all the astronauts experience the back pain that you described?

ANSWER, JERRY ROSS:

A fairly high percentage of people have some level of back discomfort, I can't really give you a percentage, it probably is 50%, it's hard to say. Yes there is a waste collection system for urination, the women have a diaper...

MARY CLEAVE:

But we're working on a better system.

JERRY ROSS:

And the men have a roll on cuff type system that has been used in high flying airplanes and things like that for a long time.

QUESTION:

Colonel Ross, you talked about doing gymnastics and gyrations up there in the assembly and disassembly, especially with EASE. Although it's not obvious from the video, I assume that at all times in EVA, you are tethered. Did you find that the tether itself interfered much with your movements or with your operations, what you had to do, and just how much of a force did it apply to you?

ANSWER, JERRY ROSS:

The tether had a restoring force of a half pound. It had been significantly reduced from previous tethers that had been used in other missions. We didn't really find it to be a problem as far as torquing us out of position and things, even though it might have, we just didn't recognize it as such. You've got to consider the tether part of your body. A lot of the protocol development work by Kitty Havens, over at Marshall and everywhere else is considering where that tether is going to be routed, where it's going to be run from, what is your translation path, you got to repeat going back that path - have you got any kind of a potential snag point. That's something you just have got to plan for. And we did that, the hardware was developed and designed somewhat in accordance with those requirements and we never had a problem. I think we got hung up a couple of times but it was never a big deal. I got it hung up behind my backpack one time, but that's when I was trying to stand on my head and look at the ground while Woody was doing something else. I came around the wrong direction and got the cable up behind my plis and it took a little while to get it out of there. But it's something you live with. Yeah, when we go on to the manipulator foot restraint on the end of the arm, it is plugged in to the arm and captured by the arm system, by the end effector. There is also another cable, or connector, or strap that goes from the end effector around to the MFR so you have a redundant means there. Then when you get into the foot restraint, as an EVA crewman you tether yourself to that foot restraint, and then you disconnect the tether that goes to the safety tether that connects over to the slideware that goes up and down the sill. So you always tether before you untether. The only time we do not tether is when we are in a free flyer such as a man maneuvering unit.

QUESTION:

This goes to Jerry as well as the PIs. I noticed on the ACCESS hardware you have knurling on the sleeves, and on the EASE hardware there was just a strip of velcro. One, do you need the knurling on the ACCESS in order to grip it and two, is the velcro, the power of velcro adequate to grip?

ANSWER, JERRY ROSS:

Yes. The knurling was required, it was there originally on the ACCESS hardware and we requested them to put a heavier knurling on. When they did that, we started running into some wear problems on the glove thermalcovers, and the safety guys got involved as well as the glove people. We took two actions: 1)to reduce the knurling, and 2)to modify the thermalcover on the gloves -both of which worked fine. The velcro that we put on the EASE beams also seemed to work satisfactorily. We would have, I think, probably preferred a knurling, but it was a manufacturing problem for them. We looked at the velcro and it seemed to be satisfactory and went with it.

QUESTION:

Having first hand experience with both the reduced knurling and better glove palms, do you think both were required, ultimately?

ANSWER, JERRY ROSS:
I'd like to go back and see what the improved glove does on the heavier knurling. What we had was satisfactory in flight and probably can stay the way it was. The improvement they made in the glove was significant as far as I'm concerned, it worked very well and is a major step forward in maintainability of hardware.

END OF DISCUSSION

NASA
LaRC **SPACE CONSTRUCTION CONFERENCE**

STRUCTURES ASSEMBLY VERIFICATION

EXPERIMENT

(SAVE)

NASA
LANGLEY RESEARCH CENTER
AUGUST 6 AND 7, 1986

RICHARD A. RUSSELL
TECHNOLOGY OFFICE
LANGLEY RESEARCH CENTER

ABSTRACT

The Space Station structure has been baselined to be a 5 M (16.4 ft) erectable truss. This structure will provide the overall framework to attach laboratory modules and other systems, subsystems and utilities. The assembly of this structure represents a formidable EVA challenge. To validate the assembly, this paper addresses a proposed STS experiment which evaluates construction techniques, assembly aids, timelines and crew workload.

INTRODUCTION

The Space Station Structures/Dynamics Technical Integration Panel (TIP) met on February 12 and 13, 1986, to develop the necessary data for an integrated structure flight experiment. As a result of this meeting, the Langley Research Center initiated a joint Langley/Boeing Aerospace Company 3 month study. This study supported the structures/dynamics TIP in developing the preliminary definition and design of a 5 M erectable space station truss and the resources required for a flight experiment.

The purpose of the study was to: (1) Devise methods of truss assembly by astronauts; (2) define a specific test matrix for dynamic characterization; (3) identify instrumentation and data system requirements; (4) determine the power, propulsion and control requirements for the truss on-orbit for 3 years; (5) study the packaging of the experiment in the orbiter cargo bay; (6) prepare a preliminary cost estimate and schedule for the experiment and (7) provide a list of potential follow-on experiments using the structure as a free flyer.

Due to the objectives of this conference, only those study activities related to on-orbit construction will be discussed. The final results of the study are being published in NASA TM 89004, "A Space Station Structure and Assembly Verification Experiment - SAVE," dated August 1986.

EXPERIMENT PRIME OBJECTIVE

THE PRIMARY OBJECTIVE OF THE PROPOSED STRUCTURAL FLIGHT EXPERIMENT IS TO EVALUATE AND DEMONSTRATE THE VALIDITY OF THE DESIGN PROCEDURES, ANALYTICAL TOOLS, FABRICATION PROCESSES, AND GROUND TEST TECHNIQUES FOR PRODUCING A HIGH PERFORMANCE, RELIABLE PRIMARY STRUCTURE FOR THE SPACE STATION.

EXPERIMENT SPECIFIC OBJECTIVES

- CONSTRUCTION TECHNIQUE OBJECTIVES
  - A. ASSEMBLY TECHNIQUE VERIFICATION
    - 1. EVALUATE ASSEMBLY TECHNIQUES UNDER OPERATIONAL ENVIRONMENTS
    - 2. EVALUATE ASTRONAUT LOCAL MOBILITY/STABILITY AIDS
    - 3. CONCEPTS VERIFICATION
      - a. PACKAGING
      - b. ERECTION FIXTURES
      - c. ASSEMBLY PROCEDURES
      - d. LARGE STRUCTURE MATING TECHNIQUES
  - B. UTILITY LINE INSTALLATION TECHNIQUE EVALUATION
  - C. EVA TIMELINE VERIFICATION
  - D. CREW WORKLOAD EVALUATION
  - E. EVALUATION OF CREW INDUCED FORCES DURING ASSEMBLY

- STRUCTURAL CHARACTERIZATION OBJECTIVES
  - A. BUILD PREDICTION CAPABILITY
    - 1. VERIFY ANALYTICAL CAPABILITY - ZERO G AND SCALE EFFECTS
    - 2. CALIBRATE GROUND TEST - STABILIZATION OF GROUND TEST FOUNDATION
  - B. DEVELOP ON-ORBIT TEST CAPABILITY FOR UTILIZATION DURING ASSEMBLY OF THE SPACE STATION
  - C. CHARACTERIZE THERMAL DEFORMATIONS AND DETERMINE "AS-BUILT" GEOMETRY IN OPERATIONAL ENVIRONMENTS
  - D. DETERMINE MATERIAL ENVIRONMENTAL SUITABILITY
  - E. ASSESS REPLACEABILITY OF TRUSS PARTS UNDER OPERATIONAL ENVIRONMENTS
  - F. ASSESS EFFECTS OF SUBSYSTEM INSTALLATIONS ON STRUCTURAL DAMPING (CABLE TRAYS, RESOURCE MODULES, ATTACHED PAYLOADS)
  - G. CHARACTERIZE CREW-MOTION INDUCED FORCES

Structures and Assembly Verification Experiment (SAVE)

Design Requirements

Truss structure

- Exhibit a torsional frequency less than 1 Hz
- Truss/Orbiter stiffness criteria
  - Construction: f >.3 Hz
  - Test: maintain lowest truss frequencies
- Primary truss loads due to test excitation and PRCS firing shall be passed through the structure to the Orbiter sills without going through the assembly fixture*

Assembly fixture

- Must withstand launch loads in the stowed configuration
- Must withstand primary thrust loads in the deployed configuration
- Accommodate rigid attachment of the truss to the STS sills for dynamic testing

Utility trays

- 2.5 meter length baseline (consider 5 meter length)
- Cross section dimensions and weights:
  - Fluid-102 x 762 mm (4" x 30"): 10.4 kg/m (7 lb/ft) total
  - Electrical-102 x 1016 mm (4" x 40"): 18.1 kg/m (12.2 lb/ft) total

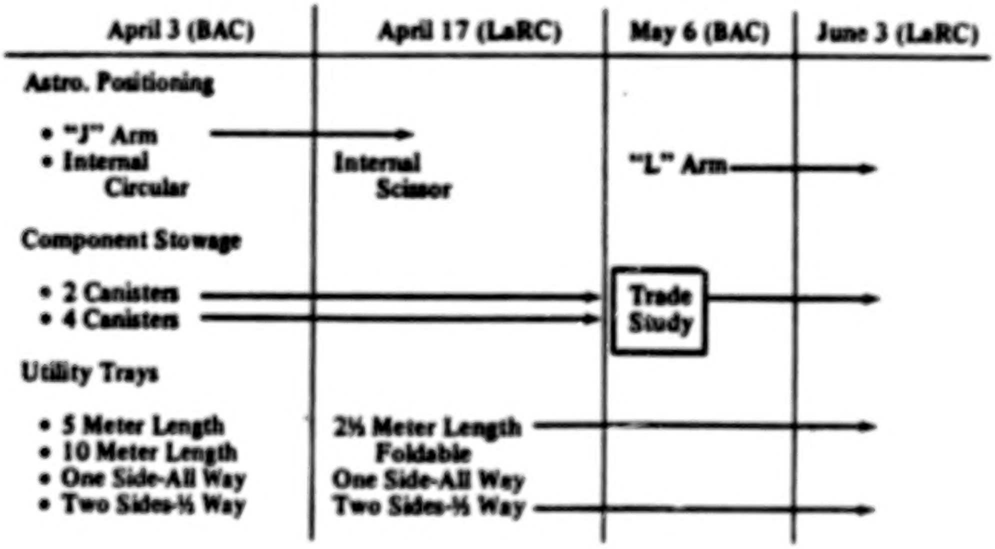
Operations

- Capable of being remotely jettisoned (2 indep., 2 fault tolerant)
- EVA reqmts limited to 2 astronauts for two 6-hr EVA periods

* PRCS firing is on contingency basis only. Loads due to PRCS firing must be limited to less than the experiment structural capability, including a factor of safety.

Structures and Assembly Verification Experiment (SAVE)

Design Evolution



April 3 (BAC)	April 17 (LaRC)	May 6 (BAC)	June 3 (LaRC)

Astro. Positioning

- "J" Arm →
- Internal Circular

Internal Scissor

"L" Arm →

Component Stowage

- 2 Canisters →
- 4 Canisters →

Trade Study →

Utility Trays

- 5 Meter Length
- 10 Meter Length
- One Side-All Way
- Two Sides-½ Way

2½ Meter Length Foldable →
One Side-All Way
Two Sides-½ Way →

Structures and Assembly Verification Experiment (SAVE)

Baseline Design Description

1.3.1 Assembly Fixture Subsystem

Assy Fixture	Component Stowage System
Astronaut Positioning System	Truss Lock-down Fixture

1.3.2 Truss Structure Subsystem

Nodes	Diagonals
Battens	Tip Mass
Longerons	Tip Mass Support Structure

1.3.3 Utility Tray Subsystem

Utility Trays, Electrical	Utility Tray Support Assys
Utility Trays, Fluid	Utility Tray Stowage Canisters

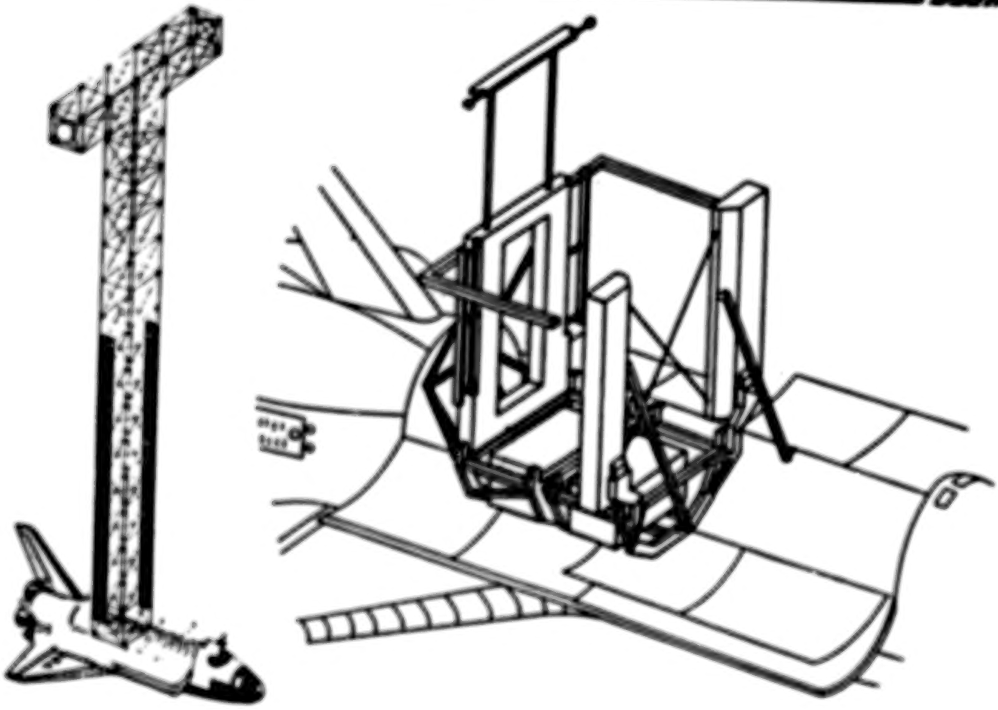
1.3.4 Instrumentation Subsystem

1.3.5 Excitation Subsystem

1.3.6 Software

Structures and Assembly Verification Experiment (SAVE)

Baseline Design Description



STOWED EXPERIMENT

The experiment is stowed with the assembly fixture rotated and locked in a horizontal position with the truss guide rails and translation mechanism retracted. The astronaut positioning arms are retracted and rotated so they are parallel to the assembly fixture frame. The truss member stowage canisters and their braces are attached to the back of the assembly fixture frame. The tip masses are attached to the forward face of the forward utility tray pallet.

SAVE
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SPACE STATION

Structures and Assembly Verification Experiment (SAVE)

Assembly Sequence

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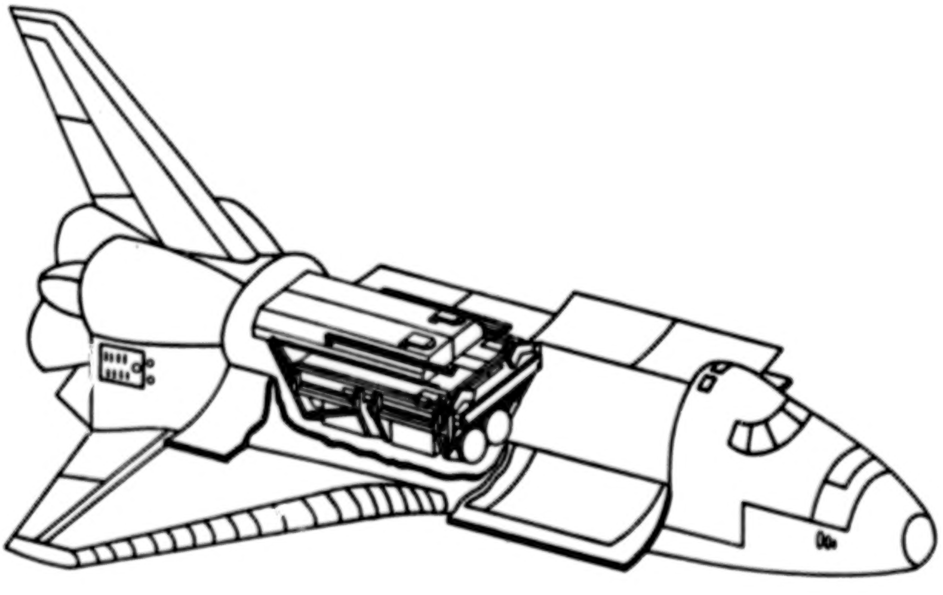

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ERECTABLE STRUT ATTACHMENT METHOD

The Space Station truss identified in the groundrules is a five-meter, assemblable truss whose struts are fifty-one mm (two in.) diameter graphite/epoxy tubes with aluminum coating for atomic oxygen protection. The truss nodes are the NASA/LaRC quick connect joints shown in the figure. The node is a machined ninety-four mm (approx. four inch) diameter aluminum ball with twenty six tapped holes for node attachment fittings. The joints are manually assemblable with a self-latching feature that allows one-handed assembly and latching. A rotating collar on the strut attachment fitting compresses internal springs that apply to preload to the joint and provides a positive lock.

SAVE
0077

SPACE STATION

Structures and Assembly Verification Experiment
(SAVE)

Erectable Strut Attachment Method

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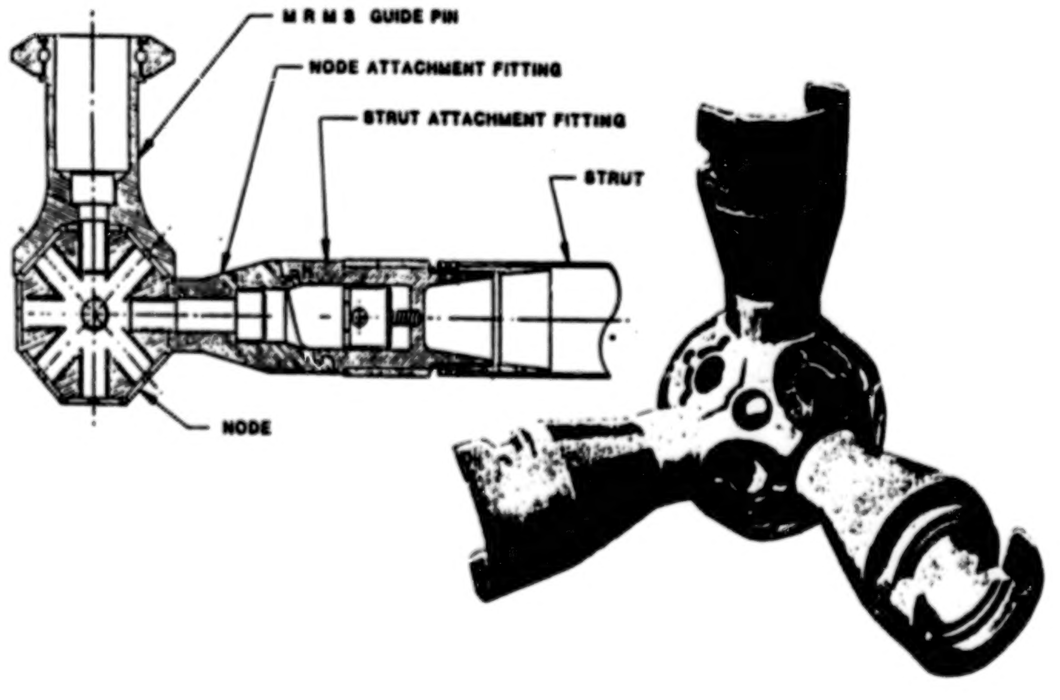

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BASELINE DESIGN DESCRIPTION

The figure on the left shows the utility tray mounting structure installed within the truss bay. It is a tubular frame structure constructed in manner similar to the truss and attached to the truss nodes at the "payload attachment" locations. Parallel vertical members spaced to accommodate the utility tray width are used for rigid attachment of the trays. The utility trays are shown as they unfold from their stowage containers within the cargo bay. Although they are shown attached to the outboard face of the attachment structure, they can be attached to either the outboard face or the inboard face.

The right-hand figure shows the truss translated two and one-half meters upward to show how the trays unfold. It may be necessary to translate the truss to this position to initiate tray installation in order to allow room for the astronauts to retrieve the first section of utility trays. Once the astronaut has obtained the free end of the utility tray, the astronaut positioning system can be used to translate both the astronaut and the utility tray to the truss for attachment.

SAVE
0078

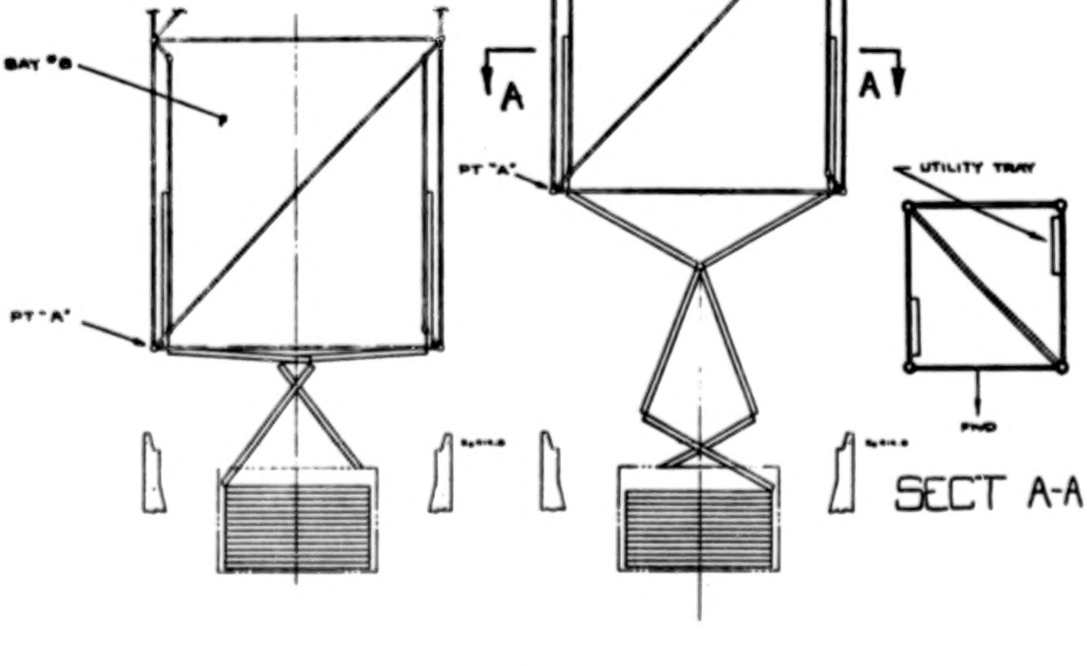
Structures and Assembly Verification Experiment
(SAVE)

Baseline Design Description

NOTES:

1. ALL VIEWS LOOKING AFT IN ORBITER PAYLOAD BAY.
2. THIS LAYOUT TO BE USED IN CONJUNCTION WITH LAYOUT L02-1673-03.

▭ LOCATION OF UTILITY TRAY INTERMEDIATE MOUNTS.



ASSEMBLY SEQUENCE

This chart summarizes the steps in the SAVE assembly sequence. The six charts that follow graphically illustrate the major steps in this process.

SAVE
0071

Structures and Assembly Verification Experiment (SAVE)

Assembly Sequence

BOEING

- Assembly Fixture Stowed in Orbiter
- Assembly Fixture Erected
- Start/Completion of "T"
- Continuation of Truss ("T" Oriented 90° to Orbiter ℄)
- End of 1st Day (Locked Down)
- Testing
- Start of 2nd Day (Assy Position)
- End of 2nd Day (Locked Down)
- Testing
- Stow Assembly Fixture

ASSEMBLY SEQUENCE

The assembly sequence begins with the Orbiter bay doors opening to reveal the packaged SAVE experiment as described in a previous chart.

SAVE
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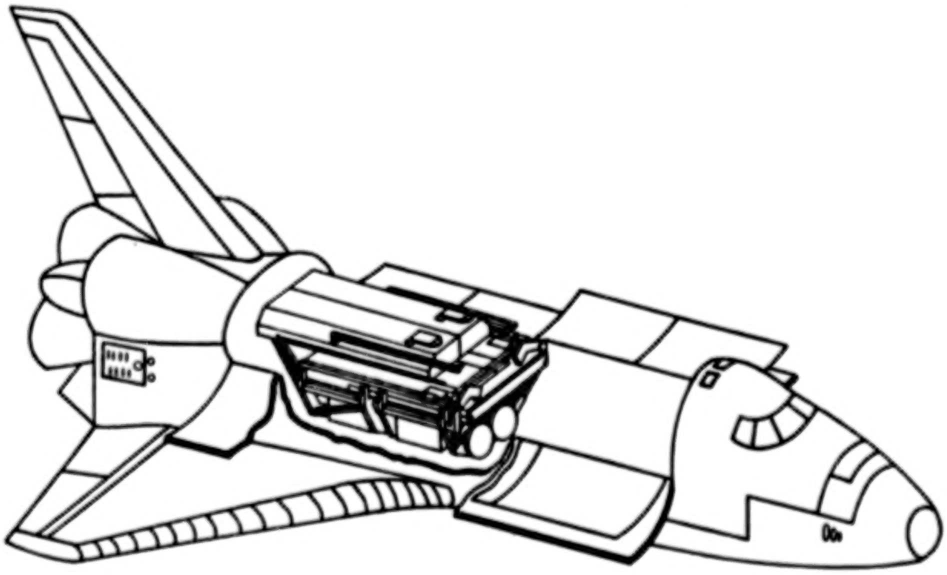
SPACE STATION

Structures and Assembly Verification Experiment (SAVE)

Assembly Sequence

BOEING



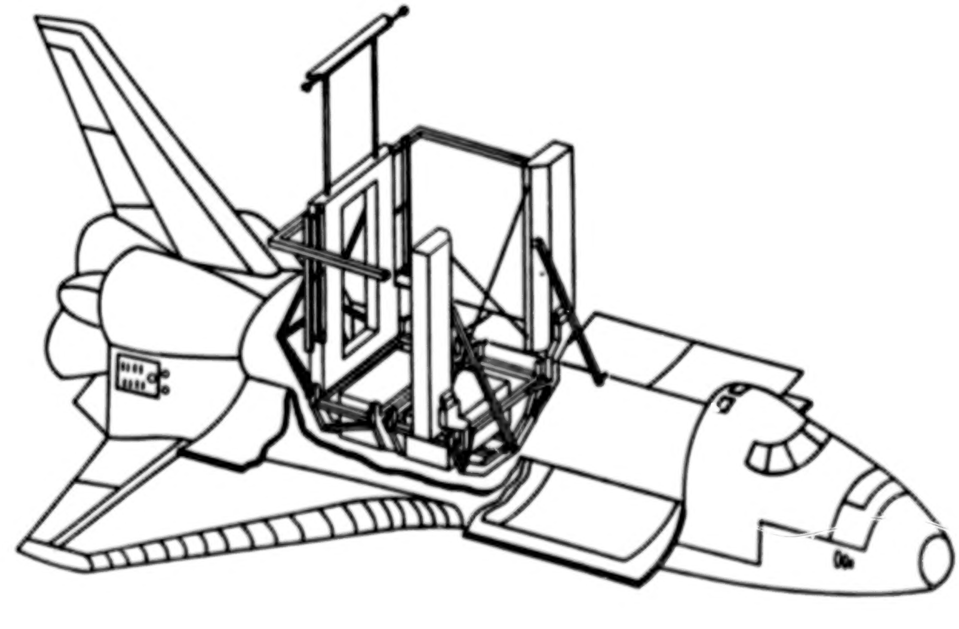
ASSEMBLY SEQUENCE

The next step is to erect the assembly fixture. This sequence shown below was established using the assumption that it can be accomplished using the remote manipulator system (RMS). (Note: with the assembly fixture in the aft portion of the cargo bay, some of the prescribed operations may not be within the reach envelope of the RMS). Automated deployment mechanisms, drives, linkages and latches, could be designed into the assembly fixture with corresponding increases in complexity, weight and cost. With either of the above methods, the assembly fixture will be ready for truss assembly before the start of the first EVA. Manual deployment by astronauts is also a possibility, but would require additional EVA time.

1. Rotate stowage canister supports into position and lock.
2. Remove stowage canisters and install into supports.
3. Rotate astronaut positioning arms ninety degrees about y-axis.
4. Raise assembly fixture to vertical position and lock.
5. Extended astronaut positioning arms (y direction) and lock.
6. Rotate astronaut positioning arms one-hundred eight degrees about y-axis.
7. Extend truss guide rails and lock.

At the beginning of the first EVA, the astronauts connect the braces between the stowage canisters and, if required, the braces from the canisters to the longerons.

Structures and Assembly Verification Experiment
(SAVE)
Assembly Sequence

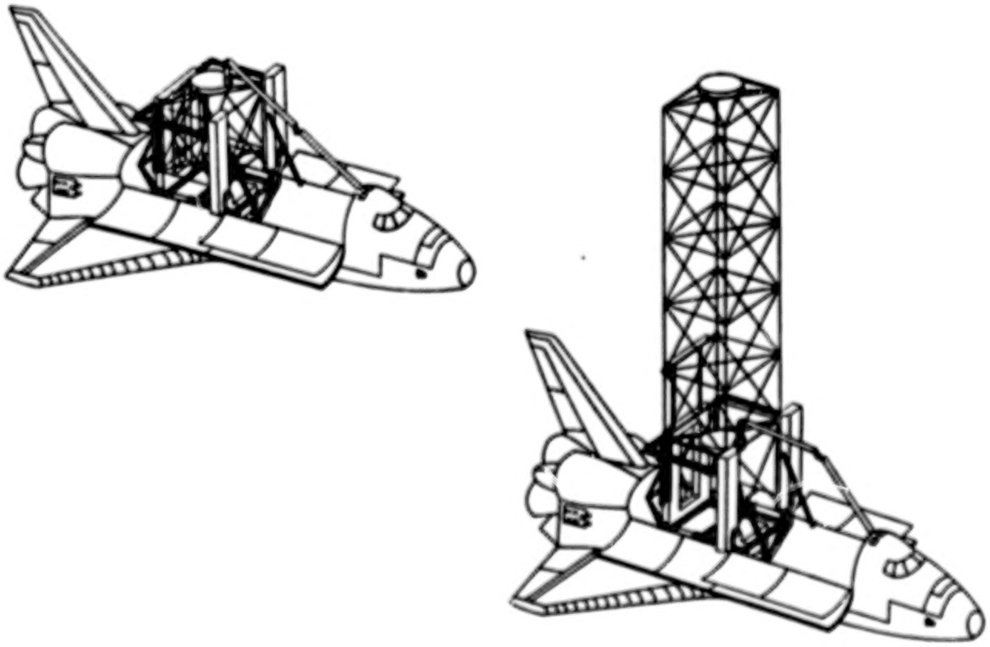


ASSEMBLY SEQUENCE

The SAVE truss assembly begins with the construction of the "T". After the completion of the first bay, the RMS is used to retrieve and position the tip mass while the astronauts connect it to the truss, as shown in the figure on the left.

Next, the truss is translated upward five meters using the truss translation mechanism, and another truss bay is assembled below it. This process is repeated until the fifth bay is assebled, with the exception of the forward batten on the fifth bay. It is omitted to provide more room for the RMS to position the other tip mass as shown in the right-hand fixture. After the tip mass is connected, the batten is installed.

Structures and Assembly Verification Experiment
(SAVE)
Assembly Sequence



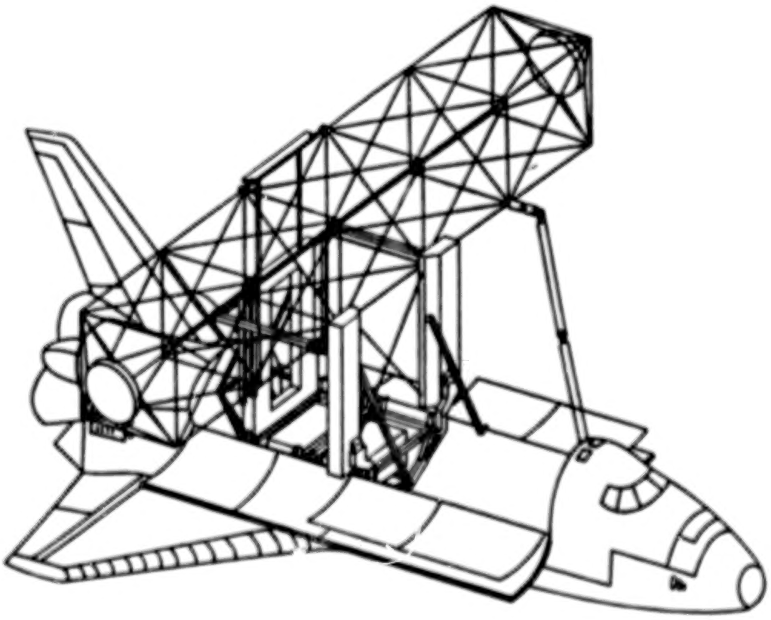
ASSEMBLY SEQUENCE

The "T" structure is removed from the assembly fixture, rotated as shown in the figure and reattached to the assembly fixture. This step is illustrated as being accomplished by the RMS using a guide pin as an attachment point. The position of the experiment in the cargo bay will determine whether the RMS reach envelope is sufficient for this task. An alternate approach is to rotate and reattach the truss manually with one astronaut in the mobile foot restraint (MFR) and the other in a foot restraint on the assembly fixture.

Structures and Assembly Verification Experiment
(SAVE)

Assembly Sequence

BOEING

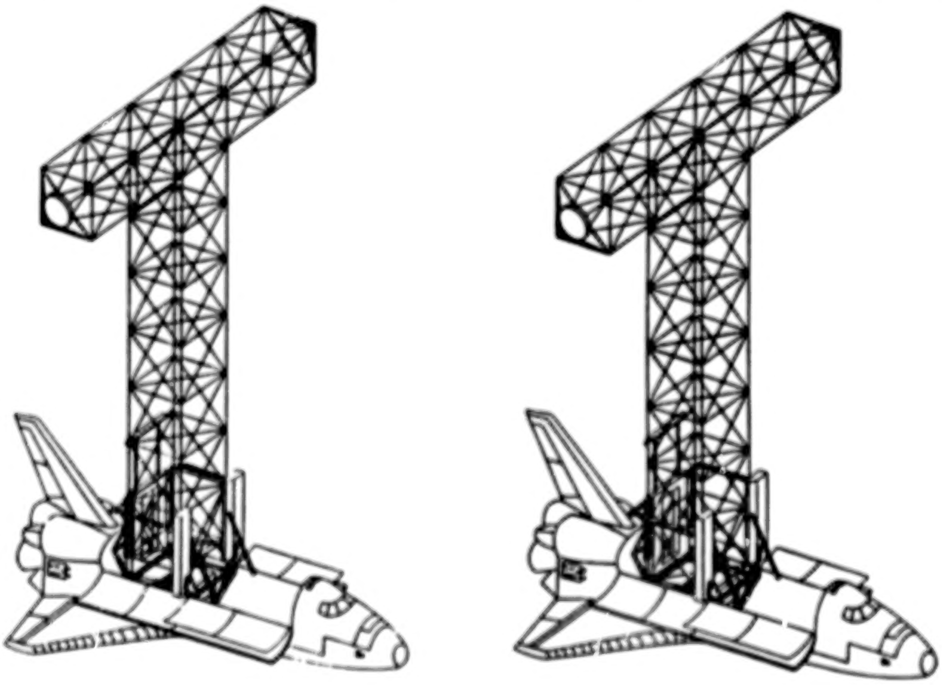


ASSEMBLY SEQUENCE

Assembly of the truss continues until seven more bays are added to the structure, as shown on the left. The truss translation mechanism is then used to translate the truss downward, and the astronauts attach it rigidly to the sill attachment fixtures. The truss translation mechanism releases its attachment ot the truss, and a section of the truss guide rail opens to prevent constraints on the guide pin located in the guide rail. The truss, as shown in the figure on the right, is now ready for dynamic tests. The completion of member-out dynamic tests concludes the first bay of EVA.

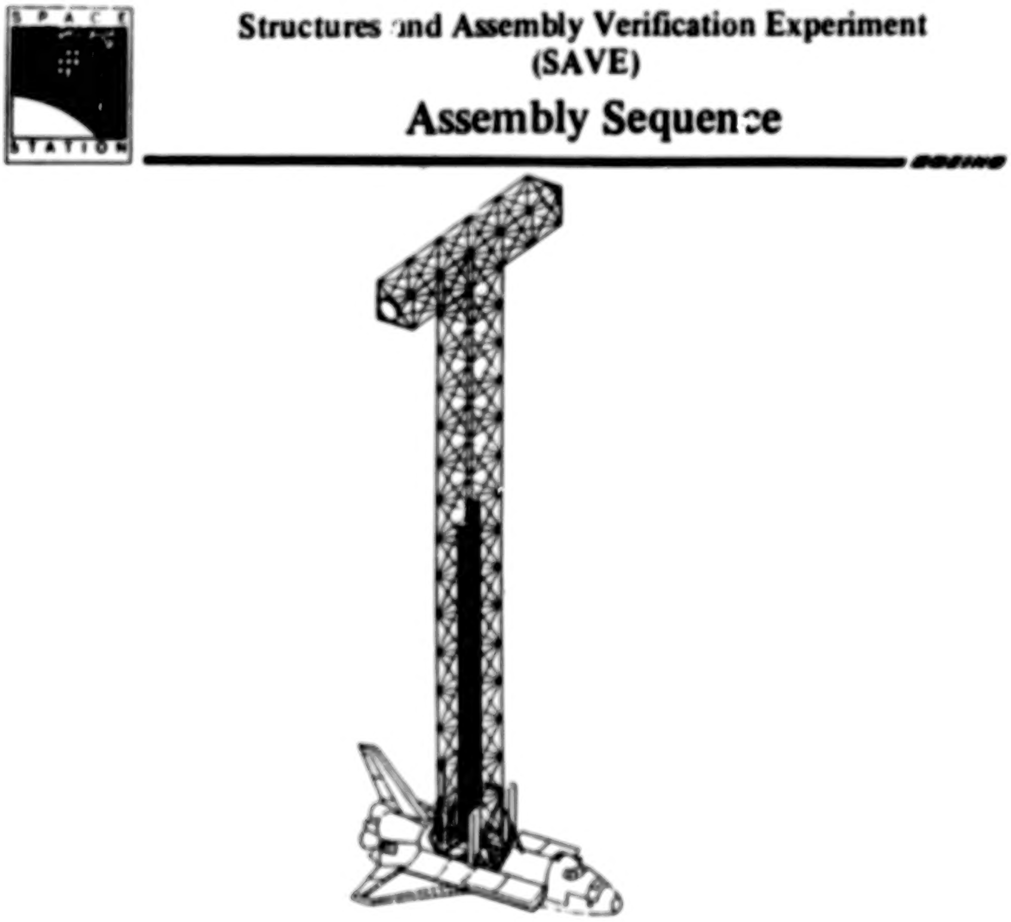
Structures and Assembly Verification Experiment (SAVE)

Assembly Sequence



ASSEMBLY SEQUENCE

The second bay of EVA begins with the reattachment of the truss guide rails and the truss translation mechanism. The astronauts then release the truss from the sill fixture, and the truss is translated upward to the assembly position. Truss assembly continues as before, except that utility trays are installed as the truss is constructed. After the assembly of eight additional bays, the truss is again lowered and attached to the rigid sill fitting for dynamic tests.



Structures and Assembly Verification Experiment
(SAVE)

Assembly Sequence

PRELIMINARY TIMELINE ASSUMPTIONS

EASE/ACCESS data and video tapes were used to establish EVA start and completion points and to determine strut and node installation timelines. Two forward located stowage containers were assumed, therefore translation of equipment from the forward to aft positions is necessary. Utility tray timelines do not include connecting wiring or fluid lines.

Manrated RMS timelines were developed prior to the EASE/ACCESS mission. These were used for determining translation times for the astronaut positioning system.

Maximum use of the RMS was assumed to reduce EVA timelines. RMS operations include erection of the assembly fixture and setup of work stations. These operations are performd prior to the start of EVA.

Structures and Assembly Verification Experiment (SAVE)

Preliminary SAVE Timeline Assumptions

- Initial EVA tasks start when battery power turned on.
- Final EVA tasks end with connection of SCU.
- No contingency time is included for problems, assumes everything goes smoothly.
- Strut and nodes times are based on preliminary EASE and ACCESS video tape analysis.
- Struts and nodes are stowed in 2 containers located forward of the assembly fixture.
- Strut and node times assume that they are presented where and when needed, in the correct order, and crewmembers do not have to egress foot restraints.
- Construction fixture and utility tray times are based on preliminary designs.
- No time alloted for connecting utility lines or wires.
- Assumes instrumentation is pre-integrated with structural members.
- Safety tether attach points are a part of the astronaut positioning system.
- No time alloted to EMU status checks or breaks.
- EVA translation velocity = .24 m/s (.8 fps)
- Shuttle RMS power up, checkout, and translation times not charged to EVA.

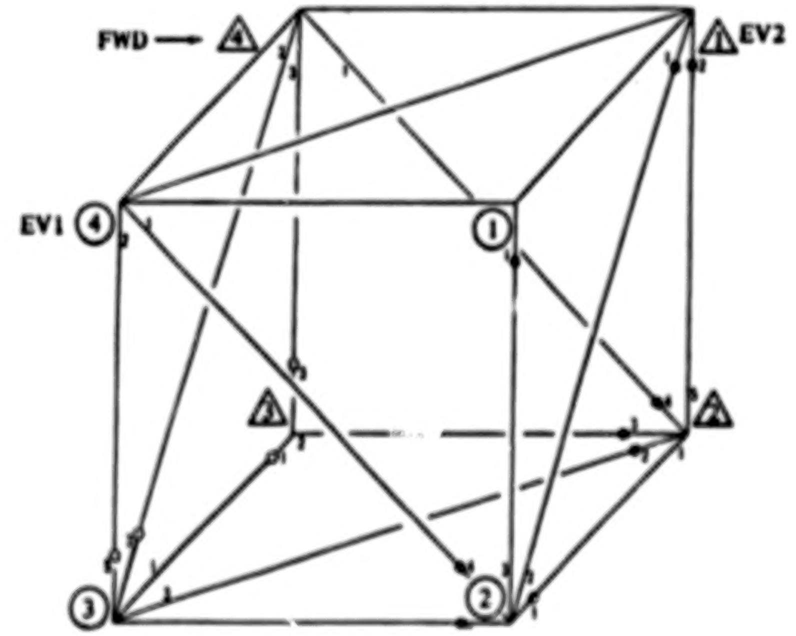
ASSEMBLY SEQUENCE

This assembly sequence represents the second and subsequent bays in a member-by-member installation sequence. The timelines of the following chart represents the assembly sequence portrayed here. The black arrows and small numbers identify the numerical order of member assembly and the position from which the astronaut performs the task. For example, EV2 installs the diagonal first and the longeron second, then moves to the lower position two and installs diagonal two, batten three and diagonal four in that order. EV1 performs similar tasks and also installs the free ends of parts that were installed by EV2, such as the first diagonal at position one.

The open arrows at the number three position depict the struts that are obtained at position two temporarily stowed and installed after the astronauts have translated to position three.

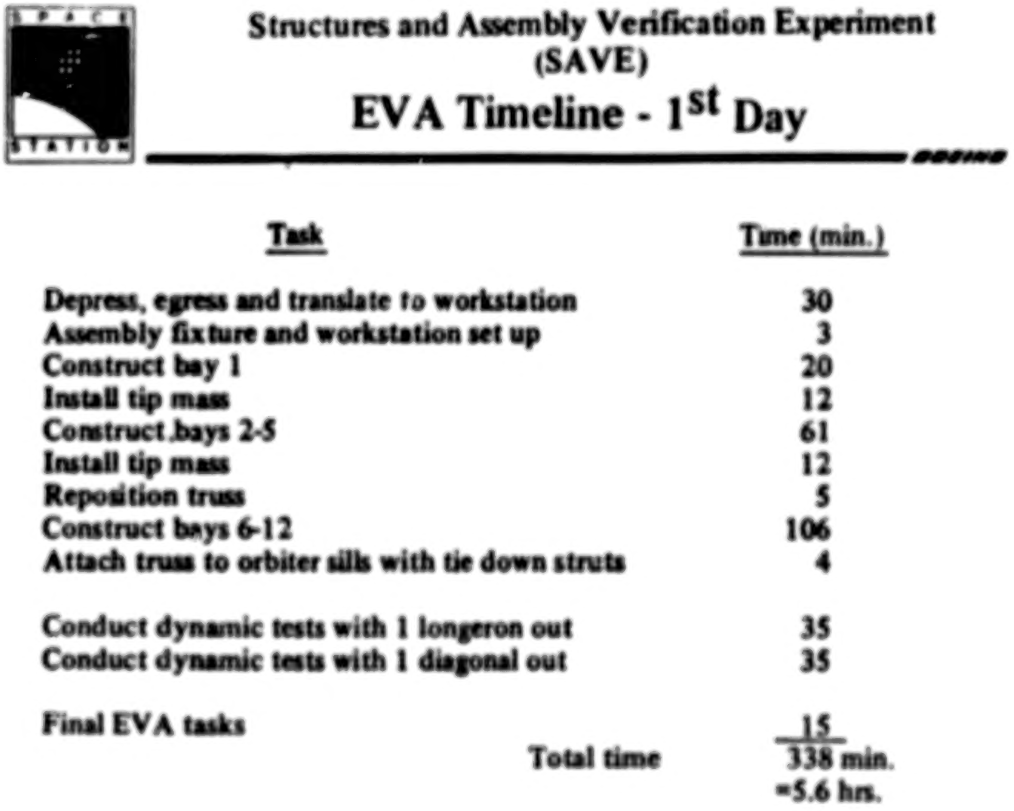
Structures and Assembly Verification Experiment
(SAVE)

Assembly Sequence (Bay 2)



EVA TIMELINE - FIRST DAY

First day timelines represent activity to construct the first twelve bays and attach them rigidly to the Orbiter sills. Also included is the assembly of the "T" portion, tip masses, and the rotating of the "T" to the horizontal position. Time has been allocated for removal and replacement of specific truss elements to support the test program. At conclusion of this EVA, half of the structure has been built, but no utility trays have been installed. The first item, translation time, was derived from study of the EASE/ACCESS times. Assembly fixture setup is accomplished in large by the RMS before EVA begins. The three minutes shown involves attaching canister braces, translating and ingress into the astronaut positioning system foot restraints. The final EVA tasks involved translation, ingress and repressurization in the airlock. The total time used is ninety-three percent of the budgeted EVA time.



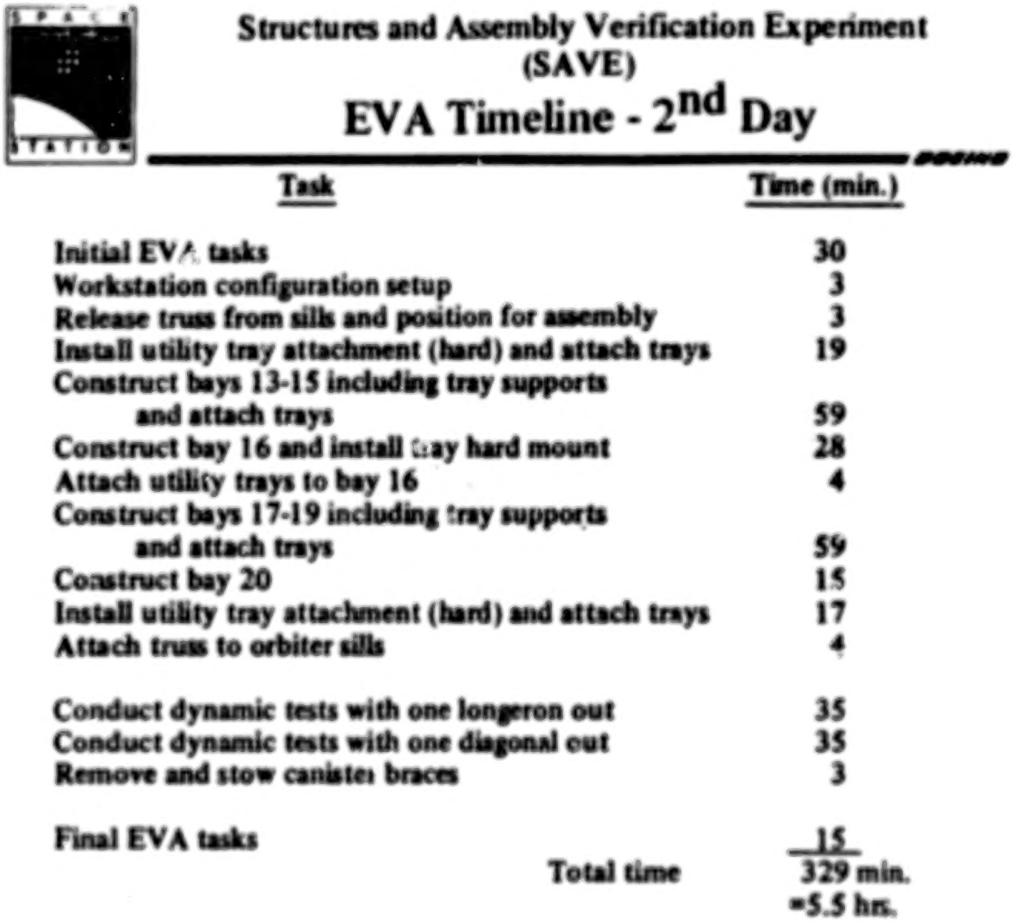
Structures and Assembly Verification Experiment
(SAVE)
EVA Timeline - 1st Day

Task	Time (min.)
Depress, egress and translate to workstation	30
Assembly fixture and workstation set up	3
Construct bay 1	20
Install tip mass	12
Construct bays 2-5	61
Install tip mass	12
Reposition truss	5
Construct bays 6-12	106
Attach truss to orbiter sills with tie down struts	4
Conduct dynamic tests with 1 longeron out	35
Conduct dynamic tests with 1 diagonal out	35
Final EVA tasks	15
Total time	338 min. =5.6 hrs.

EVA TIMELINE - SECOND DAY

Eight bays are constructed during this EVA. The first of a series of utility trays is "hard" mounted to the twelfth bay of the preceding days work. Each astronaut attaches a tray to his respective side. "Soft" tray mounts and tray attachments are installed on Bays thirteen through fifteen. Another hard mount is provided at Bay sixteen and soft mounts are located on Bays seventeen through nineteen. A final hard mount is made on Bay twenty.

The truss is attached to the sills and dynamic tests similar to the first day's EVA are conducted. The stowage canister braces are disconnected and stowed prior to ingress and repressurization. It is expected the RMS will stow the canisters and assembly fixture after the truss experiment has been jettisoned. Total time used in ninety-two percent of budgeted EVA time.



Structures and Assembly Verification Experiment (SAVE)

EVA Timeline - 2nd Day

Task	Time (min.)
Initial EVA tasks	30
Workstation configuration setup	3
Release truss from sills and position for assembly	3
Install utility tray attachment (hard) and attach trays	19
Construct bays 13-15 including tray supports and attach trays	59
Construct bay 16 and install tray hard mount	28
Attach utility trays to bay 16	4
Construct bays 17-19 including tray supports and attach trays	59
Construct bay 20	15
Install utility tray attachment (hard) and attach trays	17
Attach truss to orbiter sills	4
Conduct dynamic tests with one longeron out	35
Conduct dynamic tests with one diagonal out	35
Remove and stow canister braces	3
Final EVA tasks	15
Total time	329 min. ≈5.5 hrs.

STRUCTURAL CHARACTERIZATION TESTS

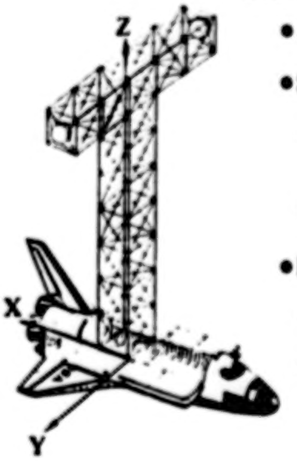
The on-orbit test configuration for the truss are shown in this figure. At the end of the first EVA, the test configuration is an eight-bay "T" (eight bays long with an additional two bays on each side to form the "T"). Static shape measurements will be accomplished to determine its as-built dimensional accuracy and to obtain thermal deflection data. Dynamic tests will be conducted to determine its dynamic characteristics and will include tests with various individual truss members removed from the bottom bay. An excitation system located in the two tip masses will be used to excite the x-z and y-z plate bending modes (actuators in-phase) and the torsion modes (x-direction actuators out-of-phase). This configuration results in test data without utility trays installed.

During the second EVA, the remaining eight bays of the truss are constructed and utility trays are installed. The static and dynamic tests are then repeated to obtain structural characterization data that include the effects of utility trays.

Structures and Assembly Verification Experiment (SAVE)

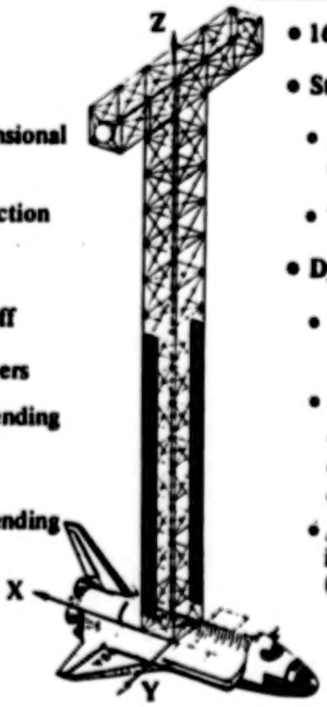
Structural Characterization Tests

1st EVA



- 8 bay "T"
- Static shape
  - As-built dimensional accuracy
  - Thermal deflection
- Dynamic test
  - Utility trays off
  - Tip mass exciters
    - X-Z plane bending
    - Torsion
    - Y-Z plane bending
- Also conduct tests with individual members out (bottom bay)

2nd EVA



- 16 bay "T"
- Static shape
  - As-built dimensional accuracy
  - Thermal deformations
- Dynamic test
  - Utility trays on lower 8 bays
  - Tip mass exciters
    - X-Z plane bending
    - Torsion
    - Y-Z plane bending
- Also conduct tests with individual members out (bottom bay)

C-4

TEST INSTRUMENTATION

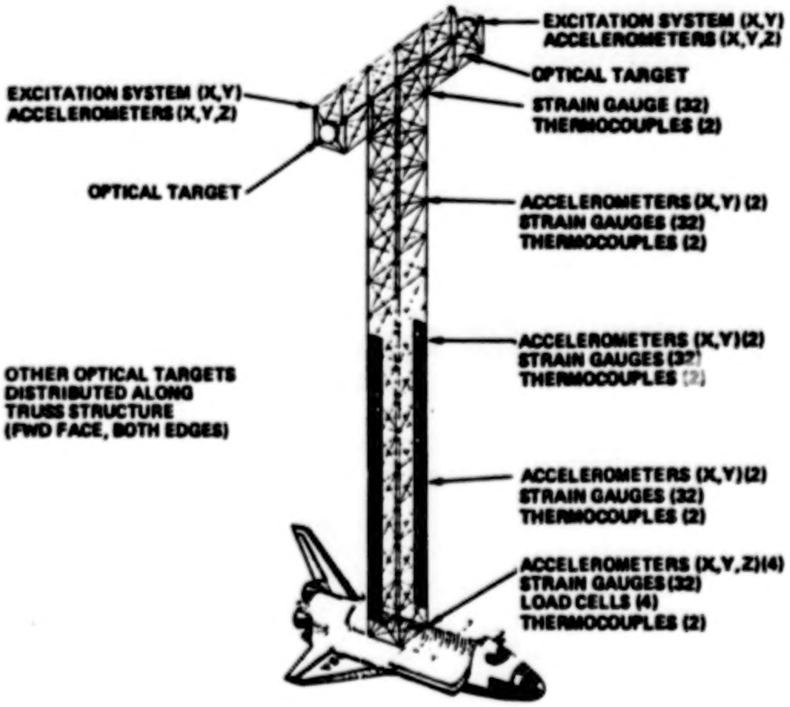
The location of test excitation and instrumentation are shown in this figure. The tip masses contain the excitation system as well as triaxial accelerometers. Strain gauges, thermocouples and other accelerometers are located at five stations along the truss. These stations are at the base of the truss and at the twenty, forty, sixty, and seventy-five meter levels. Each truss station includes two thermocouples and thirty-two strain gauges (four on each of the eight truss members). Two x and y pairs of accelerometers are located at each station except the base station, where four triaxial accelerometers are used. Load cells are incorporated into the truss mounting structure at the four truss-to-Orbiter interface points. Optical targets (retroreflectors) are placed at numerous locations on the forward face of the truss.

SPACE STATION

Structures and Assembly Verification Experiment (SAVE)

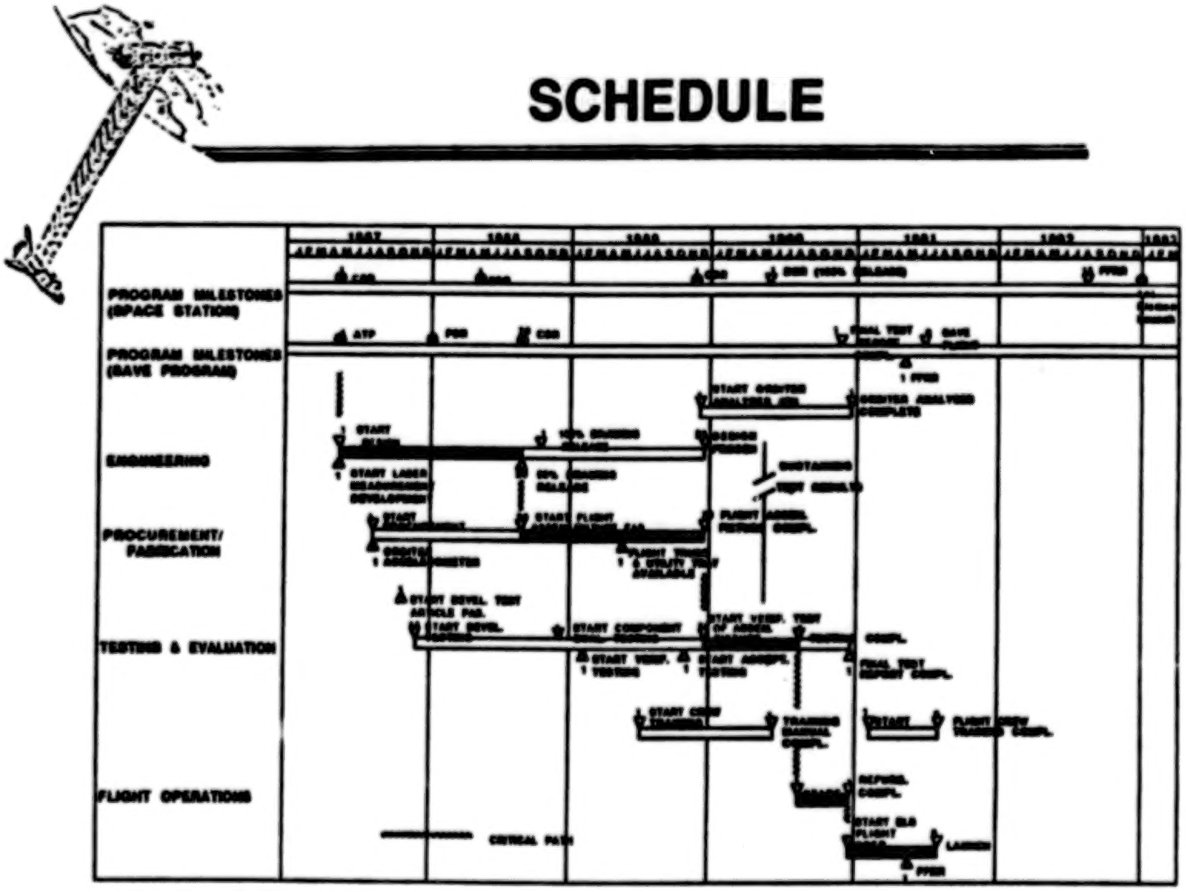
Test Instrumentation

BOEING



MASTER PHASING SCHEDULE

Authorization to proceed on the SAVE program is coincident with the contract start date for Space Station Phase C/D. The critical path is the design development, fabrication, and testing of the assembly fixture. Verification testing of the assembly fixture is achieved early enough to provide experimental data for inclusion in the integrated Orbiter/experiment model and analyses by Rockwell. Substantial analyses during design development (1987-1988) will be required to assure that no major design deficiencies are found during the orbiter integrated analyses, when there is limited schedule design deficiencies are found during the orbiter integrated analyses, when there is limited schedule recovery time. A period of three months has been allocated for refurbishment of the protoflight equipment prior to the start of Eastern Launch Site (ELS) integration. The SAVE flight date is June 9, 1991, approximately eighteen months before the first Space Station flight.



WEIGHT STATEMENT SUMMARY

This experiment weight summary is tabulated by work breakdown structure categories. The assembly fixture contributes approximately forty-two percent of the total weight and is an area where more detailed design and size of structural elements for loads and stiffness may result in significant weight savings. The other area that is subject to change is the utility trays. This weight will be determined by the Space Station design.

Structures and Assembly Verification Experiment
(SAVE)

Weight Statement Summary

	Kg	Lbs
1.3.1 Assembly fixture subsystem	3744	8266
1.3.2 Truss structure subsystem	2327	5135
1.3.3 Utility tray subsystem	2625	5793
1.3.4 Instrumentation subsystem	252	557
1.3.5 Excitation subsystem	15	33
Total	8963	19784

CONCLUSIONS AND RECOMMENDATIONS

As a result of the design effort, it is concluded that the experiment is feasible. Twenty bays of Space Station truss structure can be assembled by two astronauts in two six-hours EVA periods and tested to determine its characteristics. The experiment occupies half of the Orbiter payload bay, but its weight exceeds the established goal. The assembly fixture and procedures simulate the assembly of the Space Station truss structure.

To simplify the design and minimize weight and cost, it is recommended that assembly fixture deployment drive mechanisms be minimized and that the RMS be used for assembly fixture set-up to minimize EVA time. The ability of the RMS to accomplish this task is an area that requires more investigation.

Structures and Assembly Verification Experiment
(SAVE)

Conclusions and Recommendations

Conclusions

- **Experiment Concept Feasible**
  - **20 Bay Total**
  - **24 EVA Man Hours**
  - **On-orbit Structural Characterization**
- **Weight Exceeds 15,000 Pound Goal**
- **Stow Within ½ Payload Bay**
- **Assembly Fixture Simulates MRMS Function**

Recommendations

- **Minimize Deployment Drive Systems**
  - **Simpler Construction**
  - **Simpler Design**
- **Maximize Use of RMS**
  - **Fixture Set Up (Reduces EVA Timelines)**
  - **Repositioning of "T"**

ACKNOWLEDGEMENTS

The author gratefully acknowledges the following for their support during this three month study activity. It was their tireless efforts that the results were generated and completed in a timely manner.

Boeing Aerospace Company

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- R. Gates
- R. Glasser
- T. Shoemaker
- G. Reid
- R. Horne
- D. Jacot
- J. Coleman
- R. Watanabe
- R. Pond

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- J. P. Raney
- L. J. DeRyder
- J. Hagaman
- M. Mikulas
- D. Heard
- J. Housner
- J. Watson
- M. Lake
- D. Williams
- D. Butler
- H. Bush

Others

- E. Crawley (MIT)
- M. Kaszubowski (Kentron)
- B. Robertson (Kentron)
- M. Heck (AMA)
- J. Habermeyer (SDRC)

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Report Documentation Page

1. Report No. NASA CP-2490	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Space Construction	5. Report Date October 1987
	6. Performing Organization Code
7. Author(s) Jane A. Hagaman, Editor	8. Performing Organization Report No. L-16378
	10. Work Unit No. 506-43-4102
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225	11. Contract or Grant No.
	13. Type of Report and Period Covered Conference Publication
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report documents the proceedings of the NASA Space Construction Conference which was held at the NASA Langley Research Center, August 6 and 7, 1986. The conference was sponsored by NASA Headquarters' Offices of Space Flight (Code M), Aeronautics and Space Technology (Code R) and Space Station (Code S).

The purpose of the conference was to present to the aerospace community an in-depth review of EASE/ACCESS space flight experiments and to present a status of activities regarding future space flight experiments and accompanying technology developments that will demonstrate the capability of on-orbit construction required for Space Station.

17. Key Words (Suggested by Author(s)) Space construction Space Shuttle Extravehicular activity Neutral Buoyancy Facility	18. Distribution Statement Unclassified - Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	306	A14

NASA FORM 1626 OCT 86

NASA-Langley, 1987

END

DATE

FILMED

JAN 1 1988